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Malvern Urban Test Catchment
Volume II

Research Report No. 95

Research Program for the Abatement of Municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality

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MALVERN URBAN TEST CATCHMENT

VOLUME II

by

J. Marsalek
Environmental Management Service
Canada Centre for Inland Waters
Environment Canada

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

Project No. 73-3-12

This document may be obtained from -

Training and Technology Transfer
Division (Water)
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

Ontario Ministry of the Environment
Pollution Control Branch
135 St. Clair Avenue West
Toronto, Ontario
M4V 1P5

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Cat. No. En 43-11/95
ISBN 0-662-10687-3
BEAUREGARD PRESS LIMITED

ABSTRACT

The monitoring of rainfall-runoff events in the Malvern urban catchment was continued during 1974. A large number of rainfall-runoff events were recorded. Seventeen rainfall-runoff events were selected for further study and fairly accurately reproduced by means of the U.S. Environmental Protection Agency's Storm Water Management Model.

Late in the field season, monitoring of runoff quality was initiated. Only several runoff pollutographs were successfully recorded. These pollutographs were used to study the feasibility of simulating runoff quality in the Malvern catchment.

RÉSUMÉ

La cueillette de données sur les précipitations pluviales et les écoulements subséquents, dans le réseau d'égouts de Malvern, s'est poursuivie en 1974, année où ces phénomènes se sont produits à maintes reprises. On a retenu 17 cas de ce genre et on les a étudiés de façon plus approfondie pour ensuite les reproduire assez fidèlement au moyen du modèle de gestion des eaux pluviales de l'EPA.

Tard dans la saison, des contrôles de la qualité des eaux d'écoulement ont été entrepris. On n'a pu enregistrer convenablement que quelques graphiques du degré de pollution. Ils ont servi, par la suite, à évaluer la possibilité de simuler les propriétés qualitatives des eaux d'écoulement du réseau d'égouts de Malvern.

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CONCLUSIONS AND RECOMMENDATIONS

For most storms in the Malvern catchment, only the impervious areas significantly contributed to the surface runoff. This was the case for all the events observed, including a severe storm which produced a runoff peak at the annual level.

The Storm Water Management Model (SWMM) was calibrated for the Malvern catchment by adjusting only one model parameter - the surface storage depth on impervious areas. Other parameters were satisfactorily approximated by the default values built into the SWMM. The nature of the data did not allow calibration of the parameters describing the rainfall losses on the pervious areas.

The calibrated SWMM reproduced the selected events in the Malvern catchment with an accuracy sufficient for practical purposes.

It is recommended that monitoring of urban runoff in the Malvern catchment be continued with particular emphasis on runoff quality data. Towards this end, the Malvern instrumentation system should be modified by installing a second sampler at the monitoring station. Both samplers should be operated independently and their operation should be recorded.

Additional testing of the SWMM, particularly of the runoff quality subroutine, is also recommended.

1 INTRODUCTION

The Malvern urban test catchment was established in 1973 to provide field data on quantity and composition of runoff from a typical residential area. Such field data could be used for testing of urban runoff models and also for the assessment of the magnitude of problems caused by urban runoff, such as pollution and flooding of the receiving waters.

The objectives of the first stage of the Malvern field study, reported on in an earlier progress report [1], were to select an urban catchment and to site measuring instruments within it, to collect precipitation and runoff data, and to initiate testing of the runoff quantity subroutine of the Storm Water Management Model (SWMM).

This second volume deals with continuation of the Malvern field study in 1974. The terms of reference for the second year were defined as follows:

(a) collect data on rainfall, runoff quantity and runoff quality in the Malvern catchment;
(b) reproduce selected observed runoff hydrographs by means of the SWMM;
(c) study the feasibility of simulation of runoff quality in the Malvern catchment.

The bulk of this progress report deals with the runoff quantity data collected in 1974 and the analysis of these data. The monitoring of runoff quality was included in the terms of reference of the study in late summer (1974) and, consequently, only a limited amount of water quality data was collected during the rest of the field season. Additional runoff quality data will be presented in forthcoming progress reports.

In order to avoid unnecessary repetition reference is made, whenever possible, to the first progress report. To maintain this second report as a self-contained document, however, some minor repetition could not be avoided.

2 DESCRIPTION OF THE MALVERN URBAN TEST CATCHMENT

The Malvern urban test catchment, which is located in Burlington, represents a modern residential subdivision served by separate sewers. The location and drainage boundaries of the catchment are shown in Figure 1. It has a total contributing area of 57.6 acres.

The catchment was established in 1973 with an intention to collect hydrologic data in the catchment for about five years. The data collection season spans from April to December; the data acquisition system becomes inoperational during the winter months.

2.1 Catchment Topography

The catchment is gently sloping (slope=1%) from the northeast corner towards the drainage outfall located in the southwest corner (see Figure 1). Local slopes depend on lot gradings. Typically, front yards slope towards the streets, with slopes varying from 2% to 10%. Backyards slope away from the streets towards the drainage swales, with slopes varying from 1% to 3%. The average slope of the roads in the area is about 1%.

2.2 Land Use

The entire catchment area is zoned as single family residential. Most of the houses were built in the early sixties, with virtually all the development completed by 1964. There are no vacant lots or parks in the catchment.

2.3 Hydrologic Characteristics

Two types of catchment surfaces are distinguished in calculations of urban runoff - pervious and impervious. In the Malvern catchment, 38.1 acres are pervious and 19.5 acres are impervious.

The pervious area can be further subdivided into front yards (8.0 acres) and backyards (30.1 acres). The runoff from front yards may reach the sewer inlets in a relatively short time (10-25 minutes). Backyards drain into drainage swales running along the backline of lots and draining either onto streets or, in two cases, into sewer inlets located in backyards. The runoff from backyards is thus retarded in comparison with that from front yards.

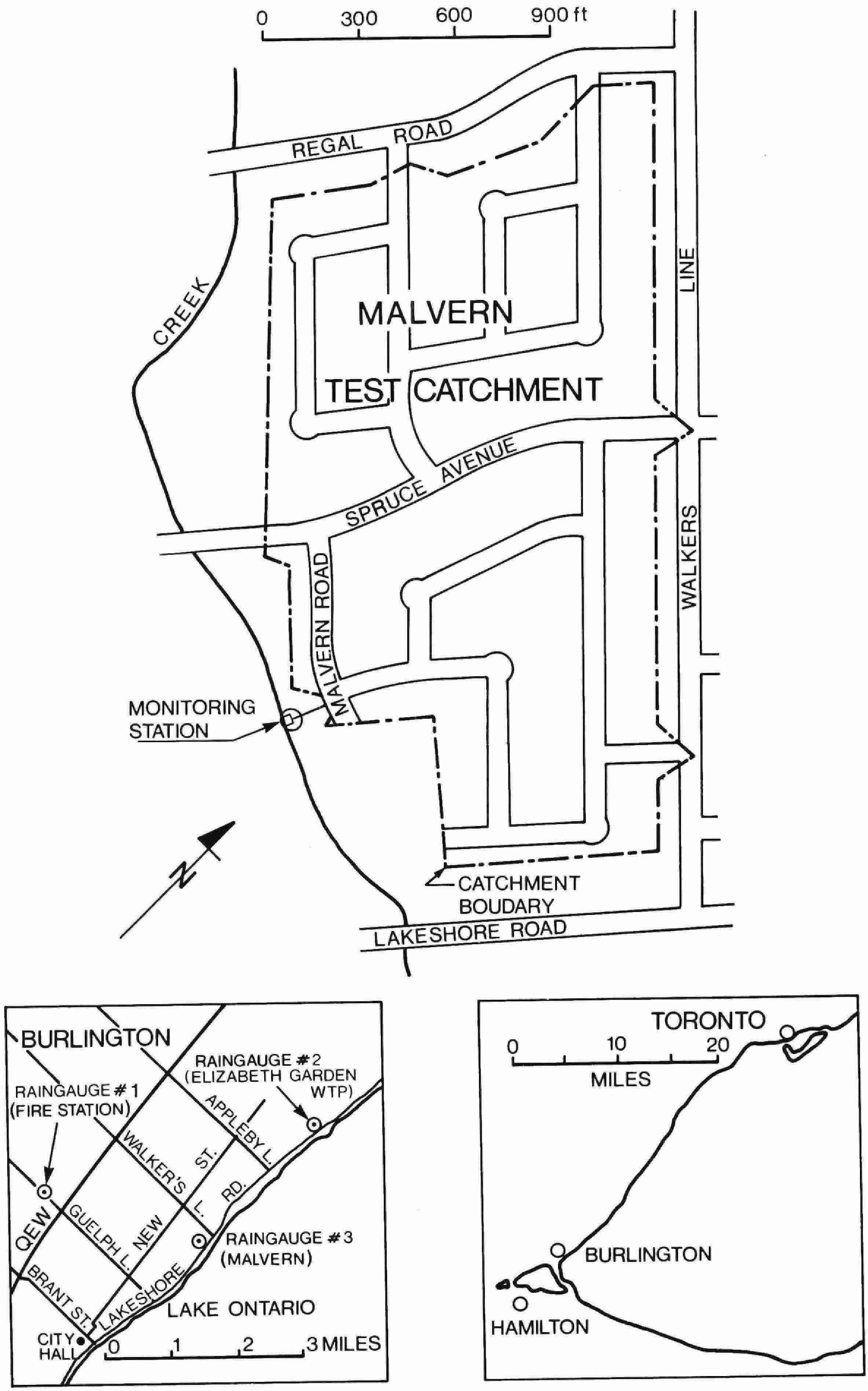

FIGURE 1. MALVERN TEST CATCHMENT-LOCATION MAP

Surface roughness of pervious areas was assumed to be characterized by Manning's n=0.25. The surface storage depth of pervious areas was taken as d=0.184 inches (0.005 m). Both these values are identical to the SWMM default values.

The infiltration capacity of the soils in the Malvern catchment was measured by means of a flooding infiltrometer. The measured capacities were somewhat higher (by 20-30%) than those calculated from Horton's formula for the following conditions:

initial infiltration rate f_o = 3.0 in/hr (0.0762 m/hr),
minimum infiltration rate f_t = 0.52 in/hr (0.0132 m/hr),
decay coefficient = 0.00115 sec^{-1}.

Since the flooding infiltrometers are known to overestimate infiltration rates, a further verification of both measured and calculated rates is required. Such a verification, by means of model calibration, was not possible in this report because the storms observed were not severe enough to produce runoff from pervious areas. Further analysis of infiltration rates will be included in the forthcoming progress reports.

The impervious areas in the Malvern catchment encompass roofs, roads, driveways and sidewalks. The total roof area is 8.1 acres with all roof leaders being connected to the storm sewers. The road surface area is 6.68 acres, with a total road length of 1.87 miles (the total curb length being 2 x 1.87 = 3.74 miles). All the driveways in the catchment are paved and drain onto roads and have a total surface area of 3.10 acres. The total area of sidewalks is 1.63 acres. Based on model calibration, the sidewalks were not considered as directly connected to the sewer system. Typically, sidewalks drain onto grass strips between the sidewalk and road. The total imperviousness of the Malvern catchment was taken as i = 17.88/57.6 = 31%. The surface storage depth of impervious areas was estimated from runoff simulations to be 0.02 inches (0.0005 m) and the roughness of the impervious surface was characterized by Manning's n=0.013.

The basic characteristics of the Malvern catchment are summarized in Table 1.

TABLE 1. MALVERN CATCHMENT SURFACE CHARACTERISTICS

	Pervious Surface		Impervious Surface			
	Malvern C	SWMM Default	Malvern C.		SWMM Default	
Area (acres)	38.1	-	19.50 (17.88 directly connected)		-	
% of total (=57.6 ac)	66.0	-	34.0 (31.0 directly connected)		-	
Ground Slope (ft/ft)	0.1 - 0.1	.03	0.1 - 0.3		.03	
Manning's n	.25	.25	.013		.013	
Surface Depression Storage (in)	.184	.184	.02		.06	
Infiltration rates -						
Maximum (in/hr)	3.0	3.0	-		-	
Minimum (in/hr)	0.52	0.52	-		-	
Decay rate (sec^{-1})	0.00115	0.00115	-		-	
Surface sub-type	Front Yards	Backyards	Roofs	Roads	Driveways	Sidewalks
Area (acres)	8.00	30.1	8.1	6.68	3.10	1.62
% of total (=57.6 ac)	13.9	52.2	14.1	11.6	5.4	2.8

2.4 Sewer System

The Malvern catchment is served by a tree-type, converging separate sewer system (see Figure 2). All the sewers are made of standard concrete pipes. The sewer system is relatively new and in good condition. The pipe roughness was estimated as n=0.013. Sizes, lengths, slopes, capacities and full bore velocities of pipes used in runoff simulations are listed in Table 2. Additional details describing the Malvern catchment, are found in first progress report [1].

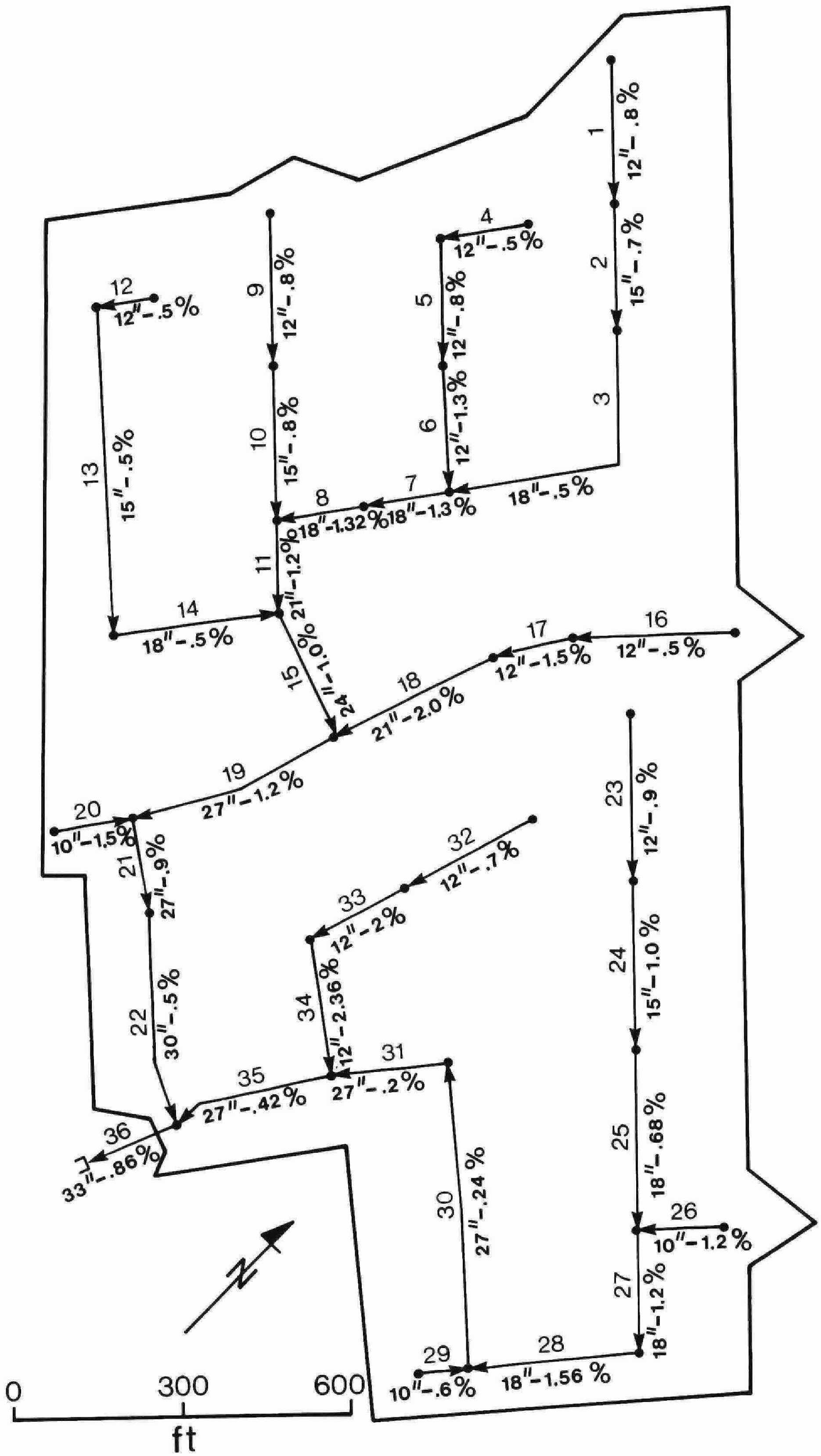

FIGURE 2. MALVERN CATCHMENT-STORM SEWER SYSTEM

TABLE 2. SEWER PIPES-BASIC DATA

Pipe Number	Drains into Pipe	Pipe Diameter (in)	Invert Slope (ft/ft)	Pipe Length (ft)	Full Pipe Capacity (cfs)	Full Pipe Velocity (fps)
3	7	18	.005	525	7.4	4.2
6	7	12	.013	213	3.9	5.0
7	8	18	.010	151	10.5	6.0
8	11	18	.0132	148	12.5	7.0
10	11	15	.008	260	5.8	4.7
11	15	21	.012	187	17.4	7.2
13	14	15	.005	292	4.6	3.7
14	15	18	.005	298	7.4	4.2
15	19	24	.010	242	31.0	7.8
18	19	21	.020	304	22.5	9.3
19	21	27	.012	384	34.0	8.5
21	22	27	.009	161	29.4	7.4
22	36	30	.005	390	29.1	5.9
25	27	18	.0068	301	8.7	4.9
27	28	18	.012	224	11.5	6.5
28	30	18	.0156	292	13.2	7.4
30	31	27	.0024	546	15.2	3.8
31	35	27	.002	194	13.9	3.5
34	35	12	.0236	238	5.5	7.0
35	36	27	.0042	280	20.1	5.1
36	outlet	33	.0086	176	49.2	8.3

3 INSTRUMENTATION AND DATA COLLECTION

Rainfall and runoff flows were continuously monitored at a single point in the Malvern catchment throughout the entire field season. The monitoring of runoff quality was initiated in late summer, 1974. A detailed description of the Malvern instrumentation was presented in the first progress report [1]. Consequently, only the new work undertaken in 1974 is reported here in detail.

3.1 Rainfall

Rainfall was measured by means of a Leupold and Stevens tipping bucket rain gauge. Tipping bucket rain gauges are considered to accurately measure rainfalls of intensities lower than 3 in/h [2]. At higher intensities, the tipping bucket will underestimate the rainfall depth because some rainfall goes unrecorded during the movement of the bucket. Consequently, it was decided to calibrate the Leupold and Stevens rain gauge for a full range of rainfall intensities. The results of these calibration tests are shown in Figure 3. It can be inferred from the calibration curve that the Leupold and Stevens rain gauge underestimated the actual rainfall depths for rainfall intensities higher than 0.65 in/h (16.5 mm/h). Such an underestimation may be caused not only by the operation of the rain gauge, but also by an improper adjustment of the bucket filling at which the bucket tips and empties one compartment.

The calibration data were applied to all the rainfall records. For high-intensity storms, the total recorded rain depth may be significantly affected by the rain gauge calibration. Typically, the non-calibrated records of the Leupold and Stevens rain gauge indicated the total rainfall depths smaller by 5%-10% than those obtained for the calibrated rain gauge. Similar results were obtained for the standard tipping bucket rain gauge of the Atmospheric Environment Service, Environment Canada.

3.2 Runoff Flow Rate

Runoff flow rates were monitored continuously by means of a calibrated rectangular weir located at the outfall from the sewer system. For flows larger than 3 cfs (0.085 m^3/s), the accuracy of the flow

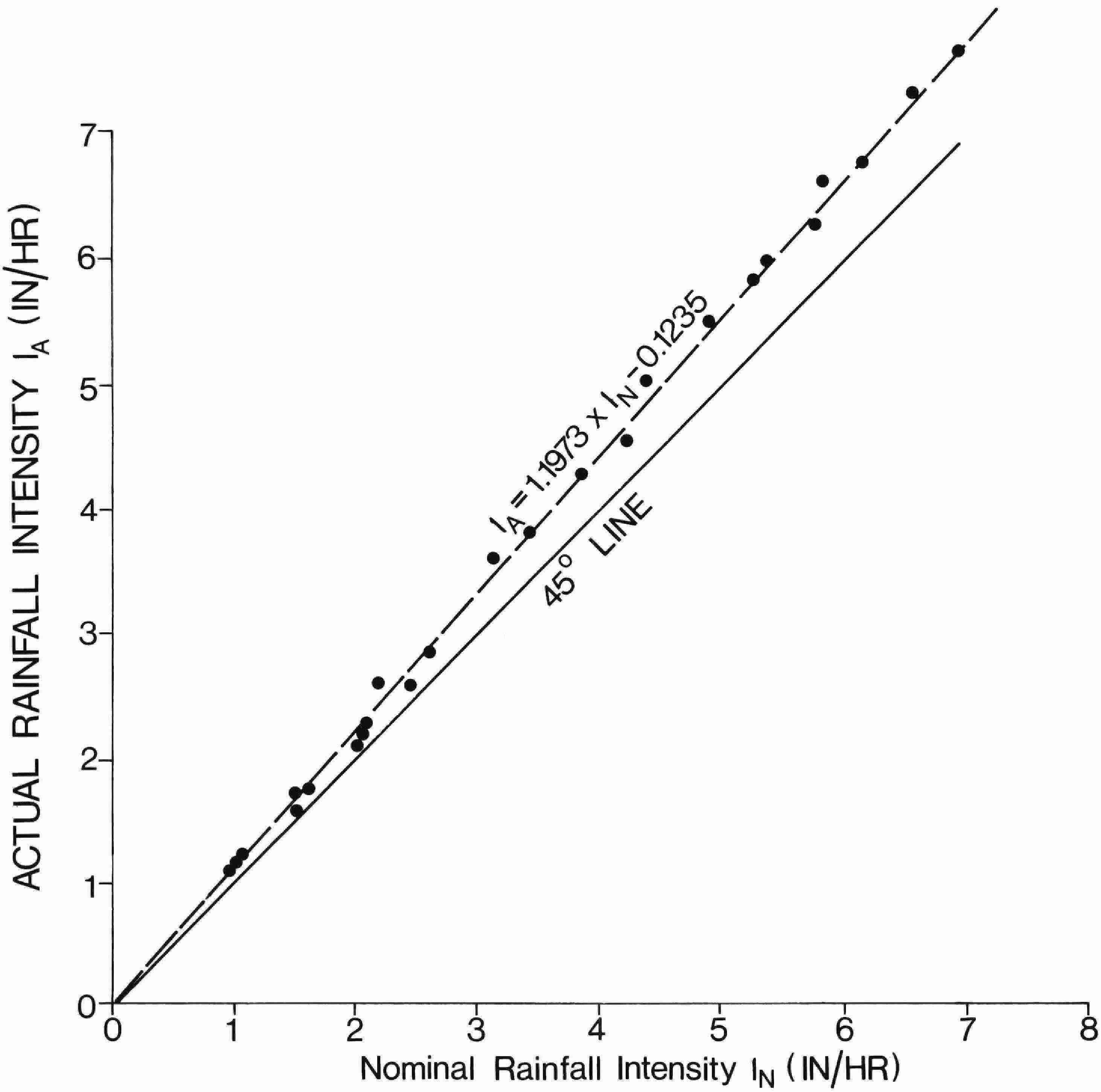

FIGURE 3. L&S TIPPING BUCKET RAIN GAUGE-CALIBRATION CURVE

measurements was better than $\pm 5\%$. Additional details of the flow measuring installation were given in the first progress report [1].

3.3 Monitoring of Runoff Quality

3.3.1 Data Collection

The terms of reference of the study were expanded in the summer of 1974 to include monitoring water quality of urban runoff at the outfall from the Malvern catchment. Towards this end, one Sirco automatic wastewater sampler (Model B/ST-VS/24A-EX) was installed at the outfall. This sampler sequentially collects up to 24 samples of one-litre volume. The sampler was switched on automatically whenever the storm water level in the measuring weir box rose 1.5 inches (0.04 m) above the zero-flow level. After this activation, the collection of samples was controlled by an internal timer which was set to a nominal five minute sampling interval (the actual interval was 6.5 minutes).

After each storm, the storm water samples were removed from the installation and brought to the Analytical Services Section, Water Quality Branch, for chemical analysis. The water quality parameters which were sampled are described in the following section. The details of analytical procedures are given elsewhere [3].

Because of a late start in the water quality monitoring program and frequent equipment malfunctions, water quality was successfully monitored for only a few runoff events. The field experience which was gained during this stage of the Malvern catchment studies was quite useful for redesigning the sampler installation in the following year and for establishing the procedures for the collection of runoff quality data.

3.3.2 Water quality parameters samples

Water quality data are difficult and expensive to collect and involve a number of considerations. For these reasons only data that are necessary to meet the study objectives should be collected. In this study, one of the objectives was to verify the SWMM and, consequently, the selection of water quality parameters was governed to large extent by the list of parameters included in the SWMM [4]. In some instances, the sample volume was not sufficient to perform all the analyses desired.

A description of the water quality parameters which were sampled in the Malvern catchment studies follows together with some comments on the relevance of these parameters to the study of urban runoff.

3.3.2.1 Common constituents and indicators. The common constituents and indicators are rarely of interest in urban runoff studies with the exception of chloride and sodium which are studied in connection with urban snowmelt. None of these constituents are included in the SWMM.

None of the common constituents and indicators were monitored in the Malvern catchment during 1974. In subsequent years, chloride was monitored on an intermittent basis.

3.3.2.2 Nutrients. Among the sources of nutrients in urban runoff, one can name organic pollution, fertilizers and automobile exhausts [2]. The principal impact of nutrients in urban runoff on the environment is their contribution to the eutrophication of lakes and impoundments and on the productivity of rivers and estuaries.

The sampling of three forms of nitrogen is recommended for urban runoff studies: nitrate + nitrite, ammonia and Kjeldahl nitrogen [2]. Nitrogen is included in the SWMM, however, without specifying the form. In the Malvern catchment, nitrate + nitrite and ammonia were routinely monitored; the monitoring of Kjeldahl nitrogen was added in a later stage of the study.

Of the phosphorus measurements, total phosphorus is included in the SWMM and was routinely monitored in the Malvern catchment.

3.3.2.3 Organic indicators. The primary indicators of organics are biochemical oxygen demand (BOD), chemical oxygen demand (COD), total oxygen demand (TOD), and total organic carbon (TOC). All these tests provide independent but non-specific measurements of organics. Two of these tests, BOD and COD, are included in the SWMM and were monitored in the Malvern catchment. BOD sampling could not be conducted on a routine basis, because of insufficient sample aliquots. Some comments on the relevance of BOD and COD tests to field studies of urban runoff follow.

Biochemical oxygen demand is a measure of dissolved oxygen depletion by biological processes. It is a laboratory test which may not truly represent in-stream conditions. Chemical oxygen demand is a measure

of inorganic and organic oxidizable materials. High COD readings as compared to BOD readings may be indicative to a large degree of organic material which cannot be utilized by microorganisms. The interest in organic material loading in storm water primarily centers on its ability to be used by microorganisms. However the extent to which BOD measurements truly reflect biodegradable organics in urban runoff has been questioned because of the presence of significant amounts of toxicants in storm water [2]. Inhibitory effects of such toxicants may strongly affect measured BOD values.

3.3.2.4 Solids. In urban areas, sediments originate from dust and debris which accumulate on impervious surfaces and also from channel erosion. Sediments are of importance from the viewpoint of water quality in that they can directly interfere with sunlight penetration and cause increasing turbidity and silting-up of fish spawning beds, and indirectly they can serve as transport media for materials such as pesticides, heavy metals, nutrients, decomposable organics and bacteria [2].

The SWMM simulates two forms of solids in urban runoff - suspended solids and settleable solids. Suspended solids are the primary constituent in SWMM simulations; settleable solids are assumed to amount to 10% of the suspended solids loading.

Suspended solids were monitored in the Malvern catchment by means of two tests. Firstly, nonfilterable residue was determined at 105°C and, secondly, fixed nonfilterable residue was determined at 550°C. Nonfilterable residue at 105°C is reported here as suspended solids. The difference between the nonfilterable residue at 105°C and the fixed nonfilterable residue (550°C) is reported as volatile suspended solids.

3.3.2.5 Trace elements. Automobile traffic as well as other factors can contribute to accumulation of various trace elements on land surface and, eventually, these elements are washed into the sewer system by surface runoff. The trace elements commonly found in urban runoff in significant quantities are lead, zinc, cadmium, mercury, copper, arsenic, chromium, iron, nickel, antimony and manganese [2]. None of these elements are included in the SWMM. However, some of these elements were monitored in a later stage of the Malvern catchment studies.

3.3.2.6 Special parameters. Among special parameters, one could name oil and grease, phenols, selected pesticides, polychlorinated biphenyls (PCB's), cyanide and possibly other parameters specific to the land use of the urban area studies [2]. Only oil and grease are included in the SWMM model. However, this parameter could not be monitored because of the need of large sample volumes for the analytical procedure.

3.3.2.7 Pathogenic bacterial indicators. Microbiological samples have to be hand collected to avoid any cross-contamination in the automatic sampler. Under a separate study, microbiological samples were manually collected in the Malvern catchment and the results were reported elsewhere [5,6]. On all storm water samples, total coliform, fecal coliform, fecal streptococcus, *Pseudomonas aeruginosa*, and fungus density estimates were performed.

4 1974 RAINFALL AND RUNOFF DATA

The field data collected in the Malvern catchment during 1974 are discussed in two sections. Rainfall and runoff flow data are presented and discussed first, followed by water quality data of runoff flows.

4.1 Rainfall and Runoff Flows

During the 1974 field season, 50 storm events with a total rainfall of 14 inches (0.356 m) were recorded. The distribution of these events according to the total event rainfall is shown in Table 3. It is obvious from this distribution that most of the monitored events were of minor character.

TABLE 3. 1974 STORMS - DISTRIBUTION ACCORDING TO THE TOTAL RAINFALL

	Total Rainfall			
	0.0 - 0.09 in (0 - 2.3 mm)	0.10 - 0.19 in (2.5 - 4.8 mm)	0.20 - 0.29 (5.1 - 7.4 mm)	>0.30 in (7.6 mm)
Number of Recorded Events	14	13	13	10

After discarding minor events and checking the validity of remaining records, 17 event records were considered reliable and were used for further analysis. Basic characteristics of these selected storm events are listed in Table 4.

With a few exceptions, the storms listed in Table 4 may be characterized as medium-intensity storms which are useful for calibration of urban runoff models and for studies of runoff quality. The selected events cover a fairly wide range of rainfall depths, intensities and durations. The maximum storm rainfall and duration were 1.29 inches (32.8 mm) and 17.8 hours respectively. The mean storm rainfall and duration were 0.46 inches (11.7 mm) and 4.3 hours, respectively. The highest observed runoff peak was 31.82 cfs (0.904 m^3/s). The recurrence interval for this flow was estimated to be about one year.

TABLE 4. BASIC CHARACTERISTICS OF SELECTED OBSERVED STORMS

Storm No.	Date	Duration [hrs.]	Total Rainfall [in.]	Total Rainfall [mm]	Total Runoff / Total Rainfall
1	May 5	2.37	0.30	7.6	0.292
2	May 8-9	17.83	1.29	32.8	0.280
3	May 15	1.50	.12	3.0	0.271
4	May 16-17	12.17	1.12	28.4	0.335
5	May 31	0.62	0.63	16.0	0.341
6	June 19	10.00	0.74	18.8	0.298
7	June 21	0.48	0.29	7.4	0.251
8	June 30	0.88	0.16	4.1	0.277
9	July 4	0.25	0.24	6.1	0.319
10	July 19	0.17	0.18	4.6	0.343
11	Sept. 2-3	9.58	0.58	14.7	0.240
12	Sept. 12	6.17	0.39	9.9	0.294
13	Sept. 28	4.67	0.30	7.6	0.249
14	Sept. 28	1.42	0.63	16.0	0.274
15	Nov. 5	1.33	0.31	7.9	0.280
16	Nov. 20	0.90	0.19	4.8	0.308
17	Nov. 20	2.00	0.30	7.6	0.323
Mean		4.26	0.457	11.6	0.293

An important aspect of data collection is quality control. Such a control starts with establishing a code of practice, reviewing the data records and, finally, reviewing the validity of data. For urban rainfall/runoff records, the ratio of total runoff to total rainfall is considered to be a good validity check [2]. Such ratios were calculated for all 17 storms and are shown in Table 4. The mean value of these ratios was 0.293. To verify this value, theoretical values of the runoff/rainfall ratio were also calculated for the Malvern catchment. Considering the high infiltration capacity of soils in the Malvern catchment and rainfall intensities of the storms observed, one would expect that virtually all the recorded runoff originated on impervious

parts of the catchment. The runoff/rainfall ratio, R, can then be expressed as:

$$R_a = \frac{V_R}{V_P} = \frac{iA \sum_{j=1}^{17} (P_j - d)}{A \sum_{j=1}^{17} P_j} = 0.296$$

where V_R is the runoff volume, V_P is the rainfall volume, P is the rainfall depth, i is the catchment imperviousness, A is the catchment area, j is a subscript, and d is the surface detention depth for impervious areas.

Comparison of the observed mean value of the runoff/rainfall ratio with that calculated by the above equation indicates that virtually all the observed runoff originated from the impervious areas of the catchment. The measured mean value of 0.293 was somewhat smaller than that reported earlier for the 1973 data. This could be explained by the fact that longer duration or higher rainfall of the 1973 storms may have resulted in some contribution of the pervious areas and, consequently, in larger values of the runoff/rainfall ratio.

4.2 Runoff Quality Data

Collection of runoff quality data was adversely affected by a late start during the field season, frequent malfunctions of the activating mechanism and automatic sampler, and power failures. Consequently, runoff quality data were collected and fully documented for only five events. Such limited data are not sufficient for any in-depth analysis of runoff quality in the Malvern catchment and, consequently, were used only for a general discussion and for establishing procedures for the later stages of the study.

Basic characteristics of rainfall/runoff events for which the runoff quality data were collected appear in Table 5. All the storms listed in this Table occurred in the fall and are characterized by small rainfall and runoff. The collection of storm water samples covered the initial part of all the storms, but did not necessarily span over the whole storm duration.

Two types of dry weather periods are listed in the table. The first set of values corresponds to the definition in the SWMM User's Manual [4] and the antecedent dry weather period then represents a sum of days during which the cumulative antecedent rainfall just equalled or exceeded one inch. The second set of values represents antecedent dry periods for any antecedent rainfall larger than 0.1 inches (2.5 mm).

A summary of runoff quality data collected in the Malvern catchment appears in Table 6. All the data are listed in the Appendix and plotted in Section 5.

The total constituent loads and mean concentrations listed in Table 6 have been compared to runoff quality data which were collected in the Malvern catchment in subsequent years. It was noted that, on the average, the loads and concentrations observed in 1974 were somewhat smaller than those observed in the later stages of the project.

TABLE 5. RUNOFF QUALITY EVENTS

Storm Number	Date	Rainfall [in.]	Rainfall [mm]	Runoff [ft^3]	Runoff [m^3]	Antecedent Dry Weather Period [Days] SWMM	Antecedent Dry Weather Period [Days] Other	Number of Samples	Parameters Monitored
18	Sept. 27	0.10	2.5	5385	153	15	3	11	COD[1]
19	Nov. 13	0.15	3.8	8319	236	7	1	24	N[2]
20	Nov. 20	0.03	0.8	535	15	16	4	9	P[3]
21	Nov. 20	0.20	5.1	11894	337	16	4	17	SS[4]
22	Dec. 7	0.12	3.0	6362	181	17	5	12	VSS[5]

[1]Chemical Oxygen Demand

[2]Nitrates + Nitrites

[3]Total Phosphorus

[4]Suspended Solids (105°C)

[5]Volatile Suspended Solids = SS (105°C) - SS (550°C)

TABLE 6. SUMMARY OF RUNOFF QUALITY DATA*

Storm	Total Constituent Load				Flow-Weighted Mean Concentrations			
Number	COD	N	P	SS	COD	N	P	SS
18	6.35	.065	.065	7.19	41.6	.43	.425	47.0
19	2.60	.248	.014	1.84	11.0	1.05	.059	7.8
20	.37	.030	.0006	.077	24.1	1.98	.040	5.1
21	17.27	.170	.057	31.18	51.2	0.50	.170	92.4
22	12.27	.088	.033	14.93	68.0	.49	.183	82.7

* mg/L

5 RUNOFF SIMULATIONS

5.1 Simulation of Runoff Hydrographs

As stated in the first progress report [1], runoff hydrographs from the Malvern catchment could be reproduced well by a calibrated Runoff Block of the SWMM. Model calibration consisted of reducing the depth of impervious surface storage from 0.06 inches (1.5 mm) to 0.02 inches (0.5 mm). Other hydrologic parameters of the Malvern catchment were approximated well by the SWMM default values (see Table 1). Consequently, the same procedure was followed in runoff simulations described in this report.

The estimates of the catchment imperviousness and surface storage were further verified against the 1974 data. These data indicate that virtually all the runoff was contributed by the impervious areas. This condition can be described by the following equation.

$$r_j = (p_j - d)i$$

in which r is the catchment runoff depth (i.e., the runoff volume per unit area); p is the rainfall depth; d is the impervious surface storage depth; i is the percentage directly-connected impervious area; and j is a subscript referring to the individual rainfall/runoff events.

In the above equation, one may consider i and d as calibration parameters and obtain an estimate of their values by fitting this equation to the observed r_j's and p_j's. Using such a procedure, the following estimates of i and d were obtained:

$i = 0.303 \pm 0.03$ (95% confidence level limits)

$d = 0.017 \pm 0.016$ (95% confidence level limits)

Since the previously established estimates of i and d (i=0.310, d=0.02) agreed quite well with those derived from the 1974 data, there was no need to amend the original estimates of i and d. However, revisions of the estimates of i and d should be made when analyzing all the data collected in this long-term study.

5.1.1 Catchment Discretization

For modelling purposes, the Malvern catchment was discretized into ten subcatchments of which characteristics are listed in Table 7. Such a discretization was found satisfactory in the previous progress

TABLE 7. SUBCATCHMENT CHARACTERISTICS

Subcatchment Number	1	2	3	4	5	6	7	8	9	10
Sewer pipe for drainage	3	6	10	13	18	21	25	30	34	22
Area (acres)	5.64	6.23	3.87	6.01	6.12	3.36	9.47	6.62	8.14	2.14
Impervious area (acres)	1.75	2.04	1.51	2.58	1.74	1.11	2.50	1.94	1.73	1.00
Pervious area (acres)	3.89	4.19	2.36	3.43	4.38	2.25	6.97	4.68	6.41	1.14
Imperviousness (%)	31.0	32.7	39.0	42.9	28.4	33.0	26.4	29.3	21.1	46.7
Catchment SWMM width (ft)	1400	2400	1390	1930	1930	1060	2550	2050	2180	1100
Length of curb (100 ft)	17.48	23.18	15.42	22.07	20.33	11.25	30.47	21.75	24.76	10.77
Number of catch basins	8	4	7	7	7	5	11	7	8	4

report [1]. Subcatchment characteristics in Table 7 reflect an earlier described modification of the directly-connected impervious area of the Malvern catchment. Observed runoff volumes indicated that sidewalks draining onto pervious areas should not be considered as a part of the directly-connected impervious area. Consequently, the subcatchment imperviousness values in Table 7 are somewhat smaller than those used in the first progress report.

Twenty-one sewer pipes out of the total number of 36 pipes were sufficient to approximate the Malvern sewer system in model simulations. Small pipes of diameters less than 12 inches (0.305 m) were neglected. This neglect resulted in some reduction of the total pipe storage volume. Such a reduction in storage was partially compensated for by increasing the diameters of some pipes along the route from the subcatchment inlet to the downstream subcatchment boundary. This was done to avoid possible sewer surcharging which would occur in model simulations but not necessarily in real life. Such a surcharging would be caused by an assumption in runoff simulations that the total subcatchment runoff enters the sewer system through a single inlet located close to the centroid of the subcatchment area. At this point, the sewer pipe is not designed to carry the total flow, since in the real sewer system the runoff flow enters the sewer through a number of inlets, and only the very downstream pipe section has a capacity sufficient to carry the total flow. Consequently, the diameters of sewer pipes No. 6, 13, 25 and 34 were increased by 3 inches (0.076 m).

5.1.2 Results of simulations

In total, 17 runoff events observed in the Malvern catchment during 1974 were reproduced by means of the SWMM. High intensity and short duration storms, such as storms No. 5,7,9,10,14,15 and 16 were simulated with short computational time steps (1 minute) and short rainfall intensity intervals (1 minute). Low intensity and long duration storms, such as storms No. 6,11,12 and 13, were simulated with time steps and rainfall intensity intervals of 5 minutes. The remaining storms were simulated with time steps and intensity intervals of 2 and 2.5 minutes. It was noted that time steps larger than 5 minutes led to numerical

instabilities in the Runoff Block model (1973 version). No sewer surcharging occurred during runoff simulations for the selected 17 events.

The results of runoff simulations are summarized in Table 8 which contains observed volumes of rainfall and runoff; simulated volumes of runoff, infiltration and surface storage; observed and simulated runoff peaks; and observed and simulated times to peak. Observed hyetographs and runoff hydrographs, and simulated hydrographs are shown, for selected events, in Figures 4-8.

5.1.3 Discussion of results

The 17 runoff events discussed in this section represent about one quarter of the total number of events to be analyzed during the entire study duration.

5.1.3.1 Runoff volumes. Accurate simulation of runoff volumes is of basic importance for good reproduction of observed hydrographs. The total runoff volumes were reproduced for the 17 selected events fairly accurately. The mean value of the ratio of measured to simulated runoff volumes was 1.00 and the standard deviation about the mean was 0.114. Both these values are comparable to those presented in the first progress report.

The mean value of the ratios of the simulated runoff volumes to the rainfall volumes (see Table 8) indicated that virtually all the simulated runoff originated on the impervious area. This is in agreement with a similar finding stated earlier for the observed hydrographs.

5.1.3.2 Runoff peak flows. The ability of a runoff model to simulate runoff peaks accurately is fairly important for drainage design. It can be inferred from Table 8 that the observed runoff peaks were slightly underestimated in simulations. The mean value of the ratio of measured to simulated runoff peak was 1.03 and the standard deviation about the mean was 0.138. Such results are slightly better than those reported in the first progress report.

The largest deviation between the observed and simulated peak was found in the case of storm No. 9. The observed peak flow was underestimated by 32%. For the same event, the simulated runoff volume amounted to only 78% of the observed volume and such an underestimation may have resulted in even larger underestimation of the runoff peak.

TABLE 8. SUMMARY OF RUNOFF SIMULATIONS WITH THE RUNOFF BLOCK OF THE SWMM ON THE MALVERN CATCHMENT

Storm Number	Rainfall Volume 1000 ft^3	Meansured Runoff Volume 1000 ft^3	Runoff Volume / Rainfall Volume	Volume of Simulated Gutter Flow 1000 ft^3	Volume of Simulated Infiltration 1000 ft^3	Volume of Simulated Surface Storage 1000 ft^3	Simulated Runoff Volume / Rainfall Volume	Measured Runoff Volume / Simulated Runoff Volume	Measured Runoff Peak Flow cfs	Simulated Runoff Peak Flow cfs	Measured Peak Flow / Simulated Peak Flow	Measured Time to Peak min	Simulated Time to Peak min	Difference Time Measured - Time Simulated
1	62.7	18.3	0.292	18.4	43.3	1.0	0.293	0.995	4.75	4.49	1.06	74	86	-12
2	269.7	75.6	0.280	81.4	187.3	1.0	0.302	0.929	5.87	5.22	1.12	965	965	0
3	25.1	6.8	0.271	6.8	17.3	1.0	0.271	1.000	4.80	4.36	1.10	30	26	4
4	234.4	78.6	0.335	72.3	161.1	1.0	0.308	1.087	25.39	22.89	1.11	510	505	5
5	131.2	44.7	0.341	39.6	90.6	1.0	0.302	1.128	31.82	39.26	.81	32	27	5
6	154.7	46.2	0.298	46.8	106.9	1.0	0.303	0.987	6.17	6.30	.98	300	305	-5
7	61.3	15.4	0.251	17.9	42.4	1.0	0.292	0.860	20.42	25.71	.79	16	13	3
8	33.2	9.2	0.277	8.7	23.5	1.0	0.262	1.057	4.95	4.73	1.05	30	28	2
9	50.0	15.9	0.318	14.4	34.6	1.0	0.288	1.104	27.21	23.78	1.14	8	5	3
10	36.7	12.6	0.343	10.3	25.4	1.0	0.281	1.223	24.08	18.17	1.32	8	8	0
11	121.3	29.1	0.240	36.7	83.6	1.0	0.303	0.793	4.86	4.71	1.03	90	90	0
12	81.5	23.9	0.294	24.4	56.1	1.0	0.299	0.980	5.58	5.82	.96	210	203	7
13	62.7	15.6	0.249	18.5	43.2	1.0	0.295	0.843	5.30	4.97	1.07	190	188	2
14	132.2	36.2	0.274	39.9	91.3	1.0	0.302	0.907	15.11	18.76	.80	9	5	4
15	64.8	18.2	0.280	18.9	44.9	1.0	0.292	0.963	6.65	7.00	.95	14	16	-2
16	39.2	12.1	0.308	11.0	27.2	1.0	0.281	1.100	7.10	6.74	1.05	10	10	0
17	62.7	20.2	0.323	18.5	43.2	1.0	0.295	1.092	8.81	7.62	1.15	43	42	1
Σ	1623.4	478.6	4.974	484.5	1121.9	17.0	4.964	17.048	208.87	210.53	17.49	2539	2522	17
Mean	95.5	28.15	0.293	28.5	66.0	1.0	0.292	1.003	12.29	12.38	1.029	149	148	3.23
Standard Deviation			0.032 10.9%				0.0124 4.2%	.114 11.4%			.138 13.8%			3.09

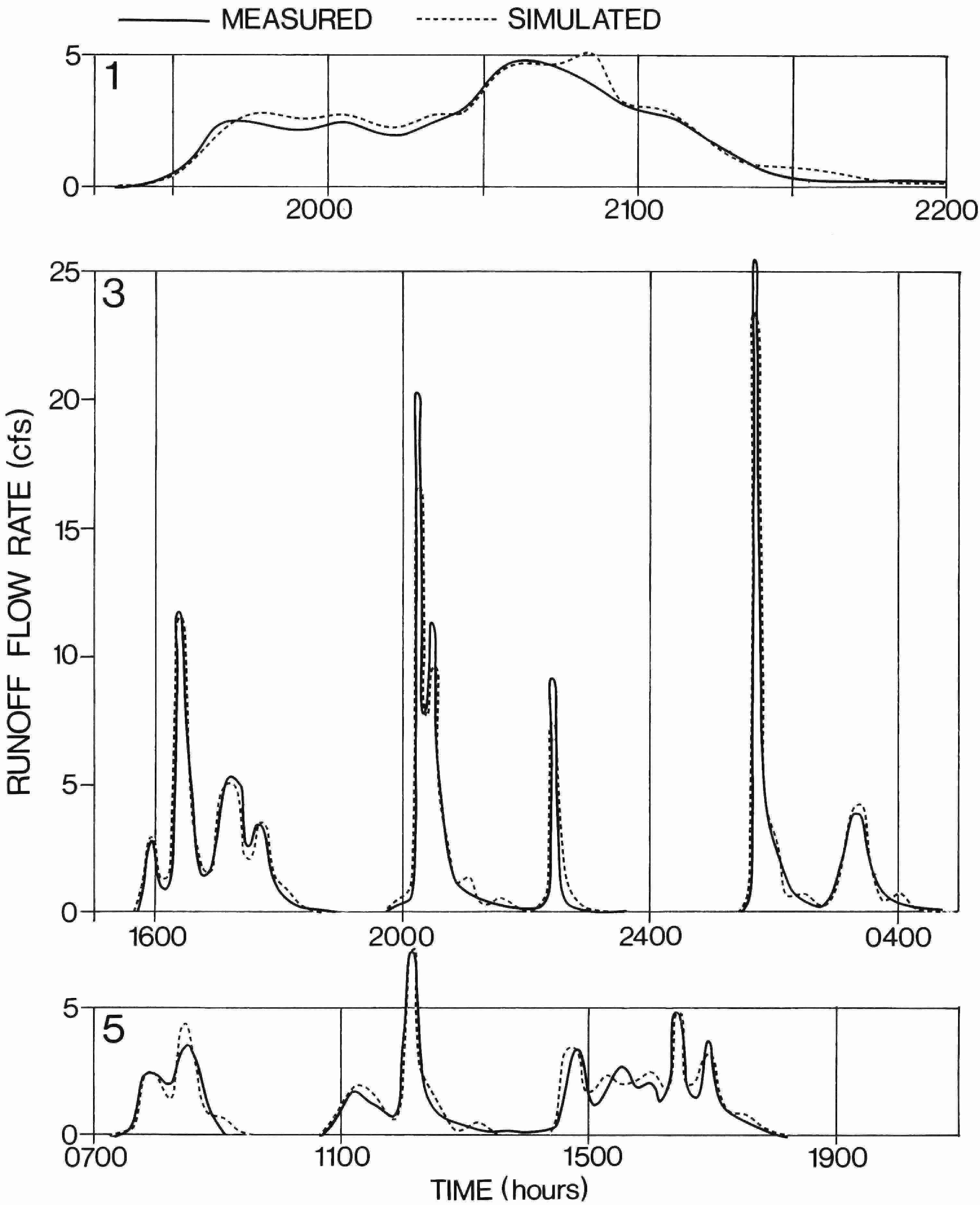

FIGURE 4. STORMS 1, 3, 5 - MEASURED AND SIMULATED RUNOFF HYDROGRAPHS

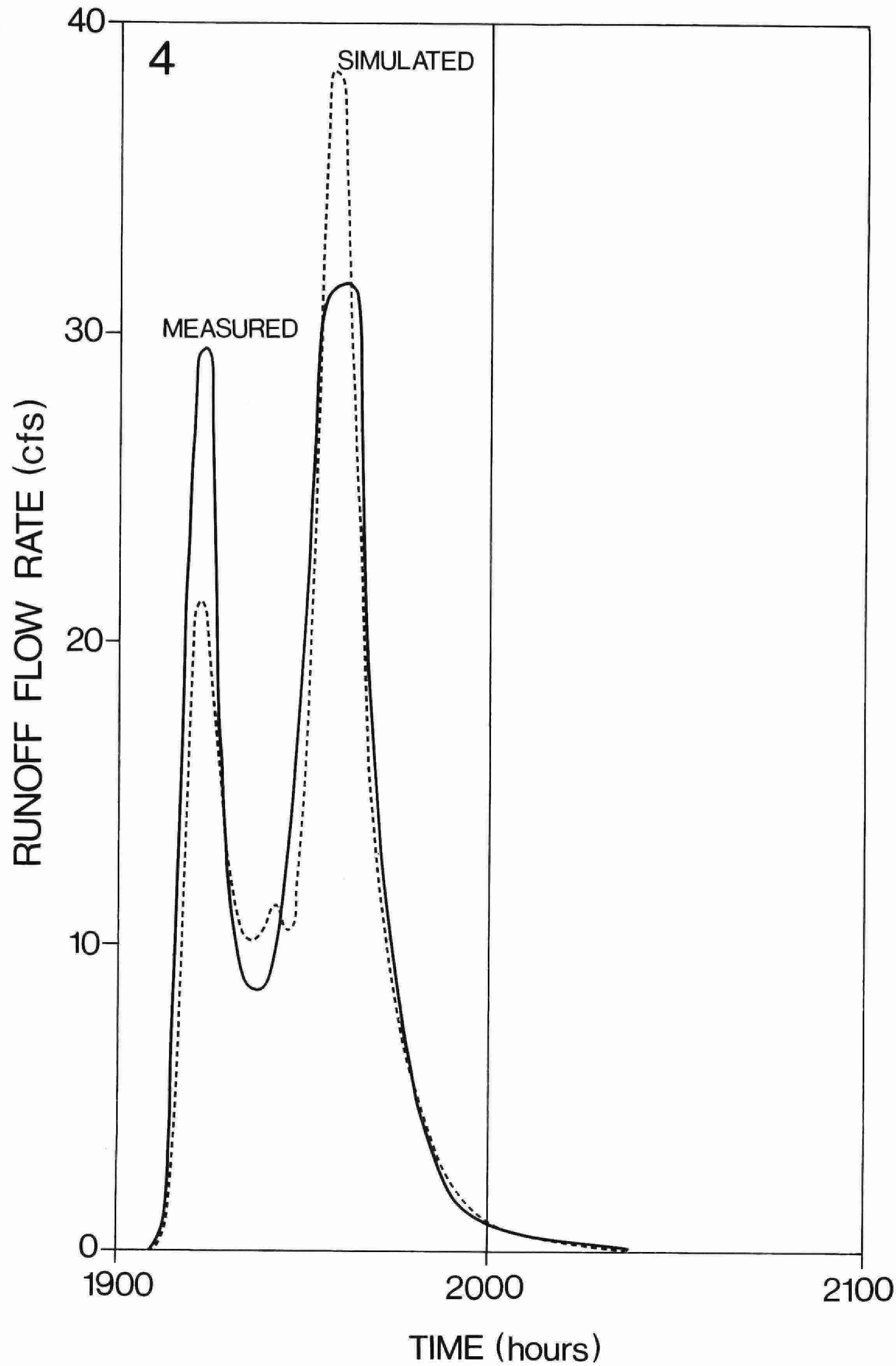

Figure 5 STORM 4 - MEASURED AND SIMULATED RUNOFF HYDROGRAPHS

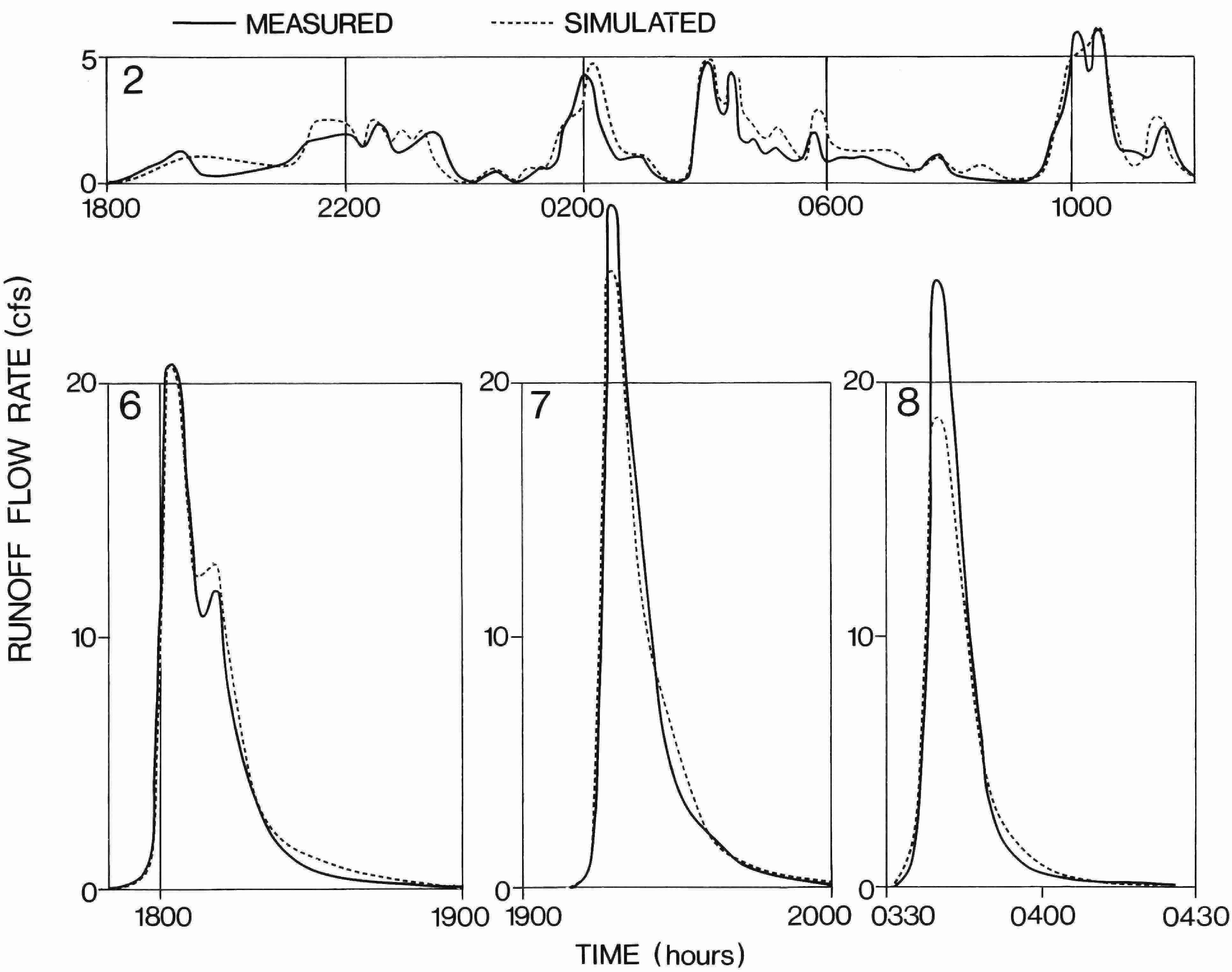

FIGURE 6. STORMS 2, 6, 7, 8 - MEASURED AND SIMULATED RUNOFF HYDROGRAPHS

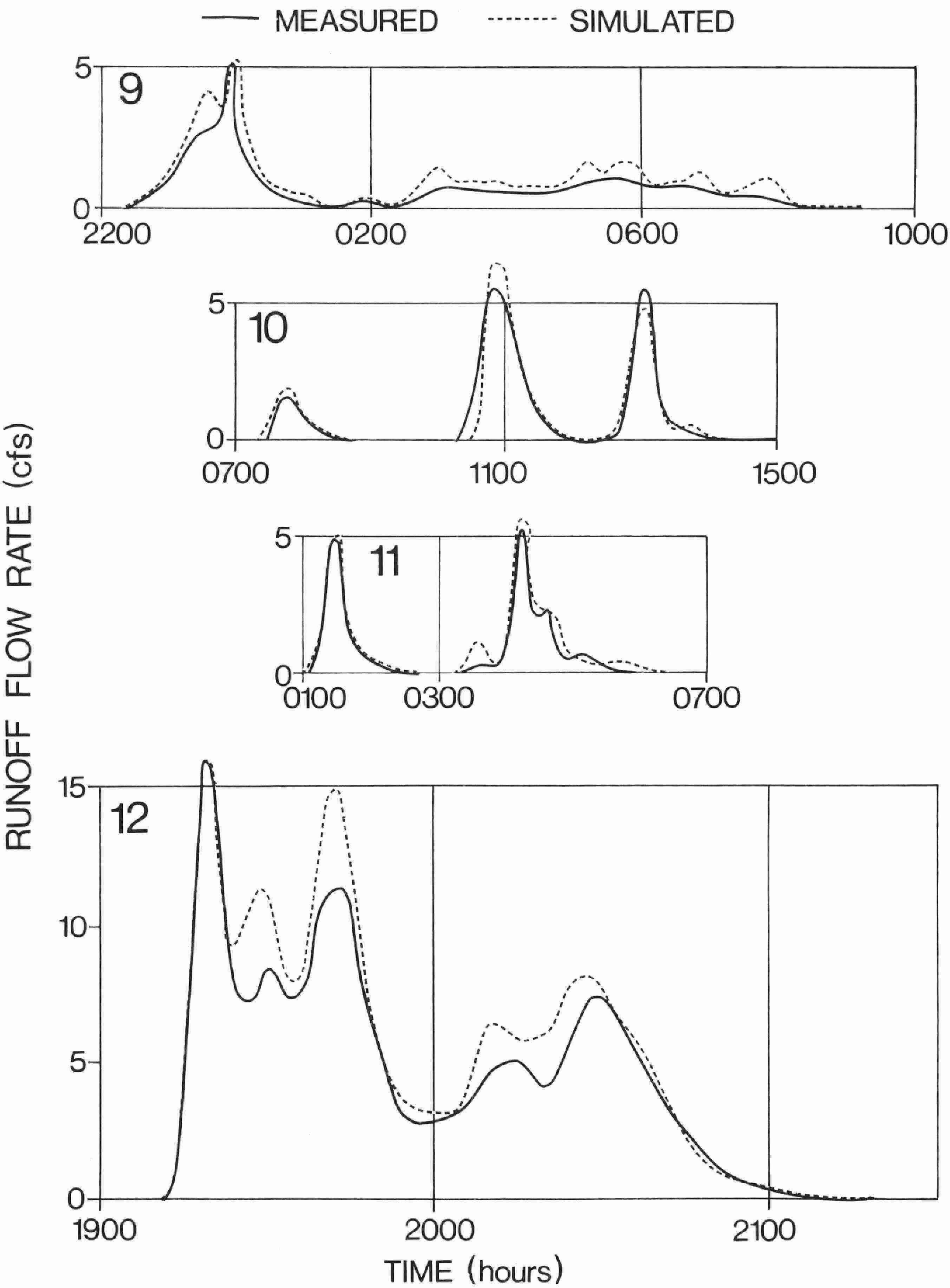

Figure 7 STORMS 9, 10, 11, 12 - MEASURED AND SIMULATED RUNOFF HYDROGRAPHS

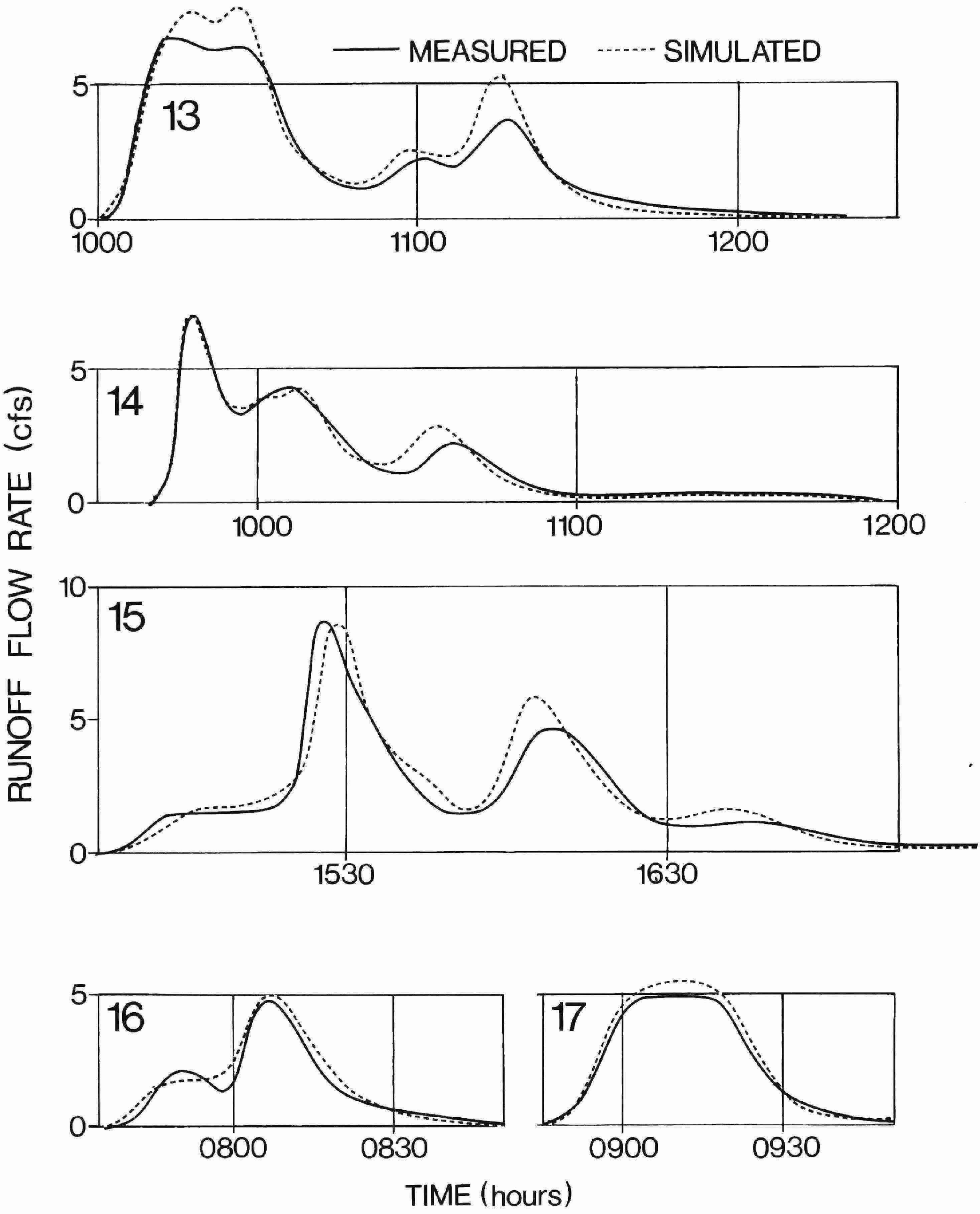

Figure 8 STORMS 13, 14, 15, 16, 17 - MEASURED AND SIMULATED RUNOFF HYDROGRAPHS

For practical purposes, the accuracy of reproduction of runoff peaks was found to be satisfactory. About 85% of all the simulated peaks were within +20% of the observed peak. This statistic will be further refined as more data becomes available.

5.1.3.3 Time to peak. The time to peak of the runoff hydrograph is, from the practical viewpoint, the least important parameter of the hydrograph. A comparison of observed and simulated times to peak for the Malvern catchment revealed that, on average, the simulated peaks occurred about 3 minutes earlier than the observed ones. This difference could be somewhat reduced by increasing the roughness of the impervious area, or by reducing the surface slopes. Both these changes, however, further reduced the simulated runoff peaks which were already underestimated. Consequently, no attempts have been made to improve the timing of the simulated peaks. For practical purposes, the agreement between observed and simulated times to peak is fully satisfactory.

5.2 Simulation of Runoff Quality

Runoff pollutographs (i.e., variation of concentrations with time) were simulated for five observed events. Two runoff quality subroutines were tested in preliminary runs. Firstly, the SWMM runoff quality subroutine was tested and, secondly, a simplified version which was developed in a previous COA study [7] and referred to as a generalized (SWMM) Quality Model (GQM). Although the pollutographs produced by both models differed slightly, these differences were insignificant in comparison to uncertainties in observed quality data. The Generalized Quality mdoel offered numerous advantages in comparison to the SWMM and was, therefore, used in this progress report. A brief description of the GQM follows.

5.2.1 Generalized (SWMM) Quality Model

The GQM is described in detail elsewhere [7]. Basically, it represents a combination of the features of the SWMM and the U.S. Army Corps of Engineers' STORM quality subroutines.

The GQM treats the area studied as a single aggregated catchment. Up to five various land uses may be specified for the catchment. For each land use, the user must supply daily dust and dirt

accumulation rates together with the proportion of each pollutant in the accumulated dust and dirt. If local data are not available, the dust and dirt rates can be quantified by means of the SWMM default values. The initial pollutant accumulation is then computed by multiplying the daily accumulation rates by the antecedent dry weather period. If appropriate, the total accumulations are modified to account for street sweeping.

Pollutants accumulated on the catchment surface are washed-off during runoff events. The wash-off rate is computed in the GQM from an exponential decay equation which is identical to that used in both SWMM and STORM. For computation of suspended solids, instead of the exponential decay equation, the user has an option to use an empirical equation which is also included in the SWMM.

The pollutant wash-off rate is a function of overland runoff flow rates which have to be supplied to the GQM as input data. For the Malvern catchment, the observed flow hydrographs were used as inputs for quality simulations. The contribution of catchbasins to the total pollutant loads can be considered by specifying the number and volume of catchbasins, and the composition of their contents. The GQM does not perform any quality routing. This seems to be acceptable for the Malvern catchment. Finally, the GQM calculates and plots pollutographs and mass curves for individual pollutants.

The Generalized (SWMM) Quality Model was found suitable for the Malvern catchment study because the GQM is fully consistent with the SWMM, can be easily calibrated, has low requirements on computer processing time and memory storage, and runoff quality simulations can be conducted independently of the quantity simulations. Since the previous studies with the SWMM quality subroutine yielded the goodness of fit with only an order of magnitude accuracy, the simplifications implemented in the GQM seem to be justified.

5.2.2 Results of quality simulations

A number of calibration runs were conducted with the GQM. The number of monitored events (five) was too small to subdivide the events into calibration events and verification events. Consequently, all the events were used for model calibration.

TABLE 9. OBSERVED AND SIMULATED POLLUTANT LOADS

		STORM NUMBER					Sum of All Storms
		18	19	20	21	22	
COD	Observed Load kg	2.60	12.27	6.35	0.365	17.27	38.85
	Simulated Load kg	5.01	9.82	7.30	0.90	15.79	38.82
	Load Obs.-Load Sim. kg	-2.41	2.45	-0.95	-0.535	1.48	0.035
N	Observed Load kg	0.248	0.088	0.065	0.030	0.170	0.601
	Simulated Load kg	0.077	0.150	0.113	0.014	0.241	0.595
	Load Obs.-Load Sim. kg	0.171	-0.062	-0.048	0.016	-0.071	0.006
P	Observed Load kg	0.014	0.033	0.065	0.0006	0.057	0.1696
	Simulated Load kg	0.023	0.0454	0.032	0.0040	0.073	0.1774
	Load Obs.-Load Sim. kg	-0.009	-0.0124	0.033	-0.0034	-0.016	-0.0078
SS	Observed Load kg	1.84	14.93	7.19	0.077	31.18	55.22
	Simulated Load kg	5.43	12.28	9.46	0.740	27.27	55.18
	Load Obs.-Load Sim. kg	-3.59	2.65	-2.27	-0.663	3.91	0.04
BOD	Observed Load kg	-	-	-	-	-	-
	Simulated Load kg	1.35	2.83	2.14	0.22	5.35	11.89

The objective of calibration runs was to minimize the differences between the observed and simulated event loads for the set of five calibration events. Using a trial and error technique, this objective was achieved in run No. 6 of which results are summarized in Table 9.

It can be inferred from Table 9 that the total events loads were reproduced fairly closely for the five events studied. This agreement, which is considered good for runoff quality data, was obtained after a fairly extensive calibration. The accumulation rates and composition of dust dirt were found to be very powerful factors in calibration of event loads.

Daily accumulation rates of individual pollutants can be calculated from the accumulation rates of dust and dirt, and from the composition of dust and dirt. Such calculations were conducted for the standard SWMM default values as well as for the calibrated rates used in this report. The results of these calculations appear in Table 10.

TABLE 10. DAILY POLLUTANT ACCUMULATION RATES IN MALVERN CATCHMENT

	BOD (kg)	COD (kg)	N (kg)	P (kg)	SS (kg)
SWMM Default Value	0.31	2.51	0.030	0.003	62.8
GQM Calibrated Values	0.28	4.18	0.063	0.018	56.5

Finally, observed and simulated pollutographs are shown in Figures 9 and 10; numerical values of pollutant concentrations are given in the Appendix.

5.2.3 Discussion of results

Total event loads from the Malvern catchment were reproduced fairly well by a calibrated GQM. This good reproduction was obtained by increasing the accumulation rates of COD, N and P, and reducing the rates for SS (see Table 10). A detailed examination of the model output revealed that the washed-off pollutant amounts represented only a minor

fraction of the pollutant accumulations on the catchment surface. Under such circumstances, even minor changes in the factors affecting the pollutant wash-off rates can lead to large changes in the total loads. It is unlikely then that the goodness of fit reported here could be repeated, without further calibration, for other events which would differ substantially from those considered in calibration. For example, events with high-intensity rainfalls would produce very large wash-off rates and, consequently, would overestimate the pollutant loads.

Definitions of the antecedent dry weather period require further study. If one adopts the SWMM definition of the antecedent period as a sum of antecedent days during which the cumulative rainfall just equalled or exceeded one inch [4], unrealistically high pollutant accumulations prior to the storm are obtained. Such accumulations were calculated for the Malvern catchment and are listed below in Table 11 for an average antecedent period of 15 days.

TABLE 11. POLLUTANT ACCUMULATIONS IN THE MALVERN CATCHMENT FOR ANTECEDENT DRY WEATHER PERIOD OF 15 DAYS

	COD (kg)	N (kg)	P (kg)	SS (kg)
SWMM Model (non-calibrated)	38.1	0.46	0.05	954.6
GQM Model (calibrated)	63.5	0.96	0.28	858.8

These pollutants are then washed-off at highly varying rates which depend on rainfall and runoff intensity. Good results were reported in a previous study [8] in which the antecedent dry weather period was defined as the period between the event studied and the first antecedent event having a rainfall larger than 0.1 inches (2.5 mm).

The pollutographs observed in the Malvern catchment were reproduced rather poorly in simulations with the GQM. The simulated pollutographs indicated fairly constant concentrations throughout the storms. Although it was possible to change the shape of simulated pollutographs by adjusting the wash-off coefficient "b" and by including

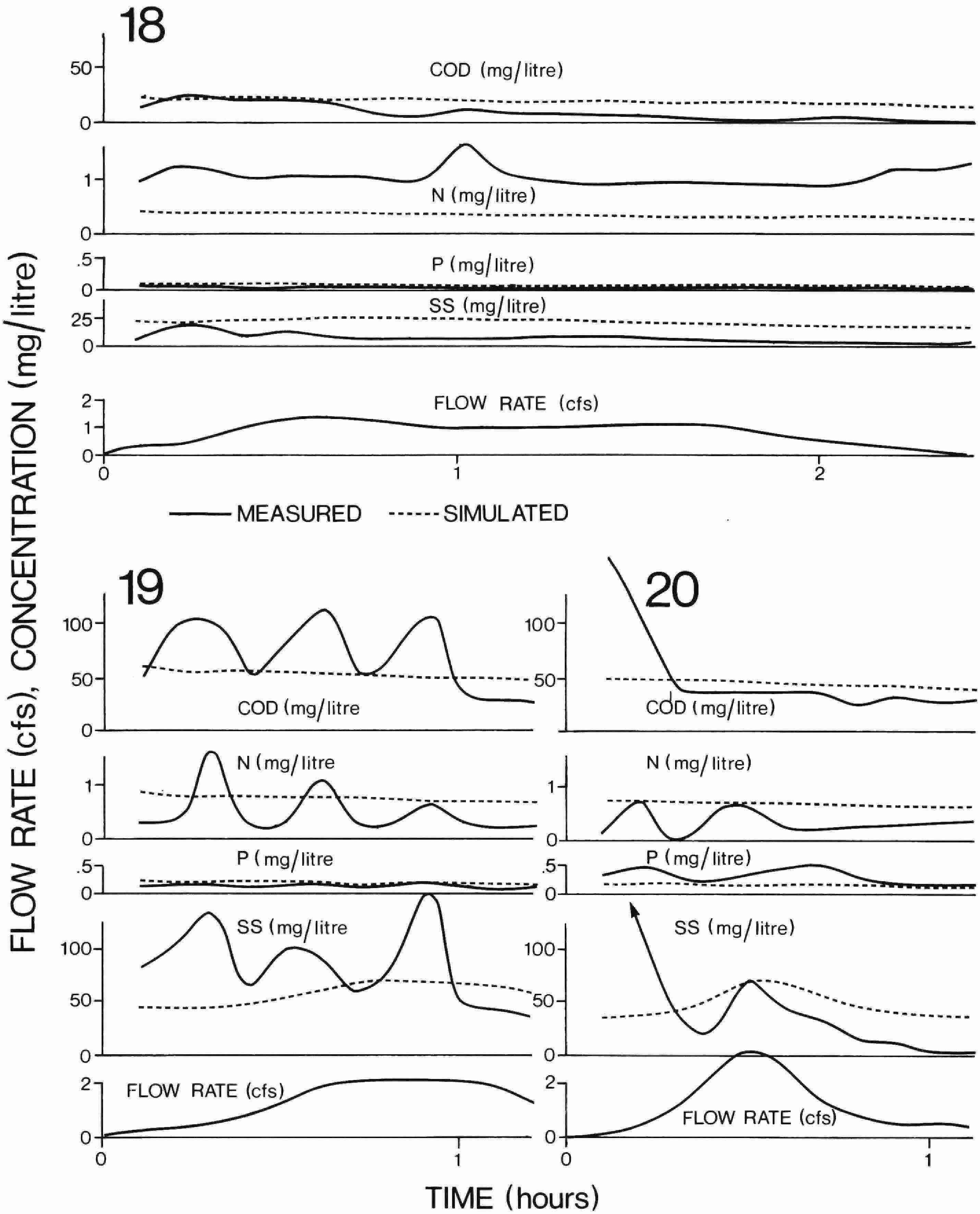

FIGURE 9. STORMS 18, 19, 20 - MEASURED AND SIMULATED POLLUTOGRAPHS

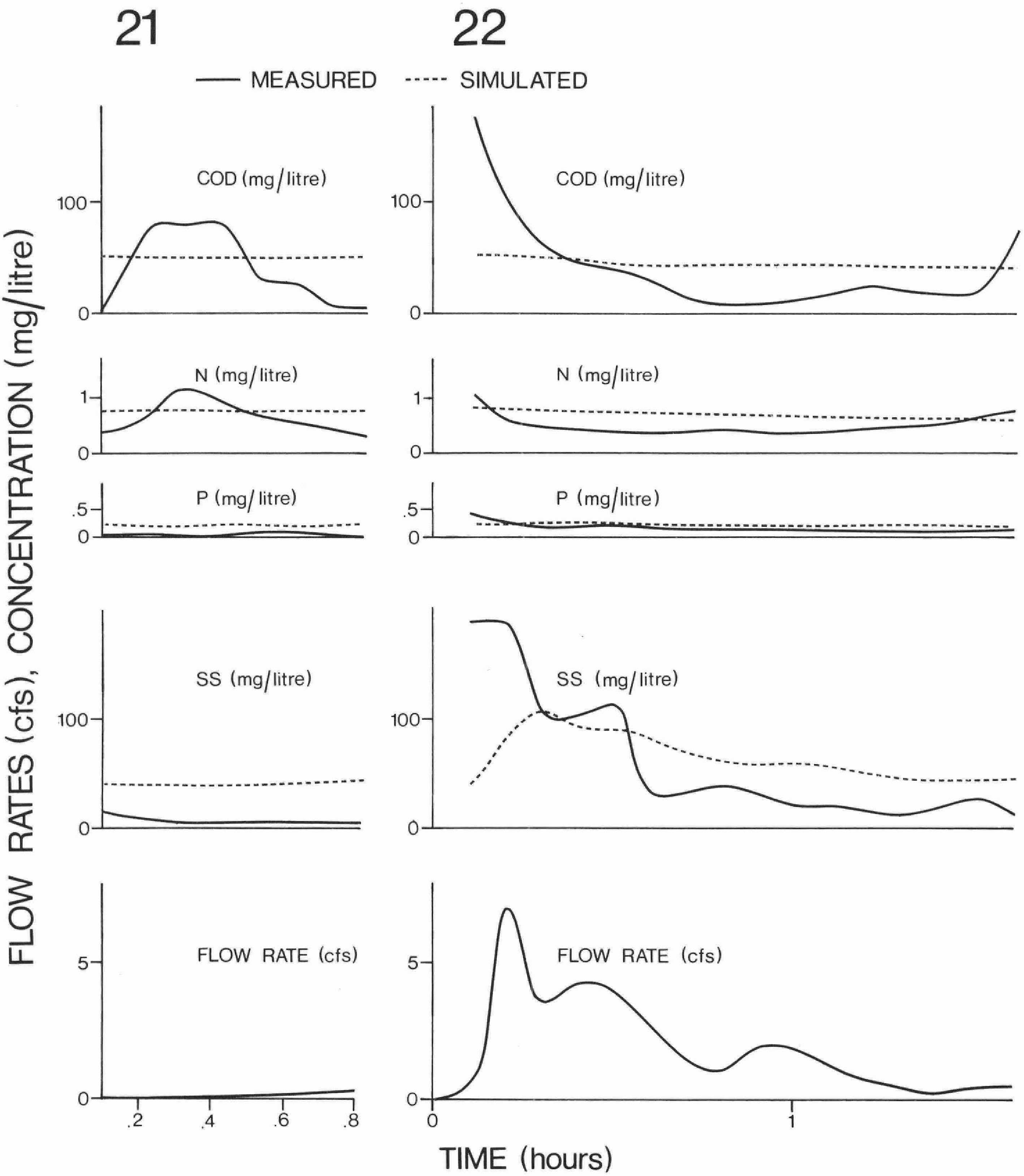

FIGURE 10. STORMS 21, 22 - MEASURED AND SIMULATED POLLUTOGRAPHS

catch basins in the simulations, the total pollutant loads became grossly overestimated. Consequently, attempts to change the shape of the simulated pollutographs were abandoned.

Comparison of SWMM and GQM simulations indicated that SWMM produced the event loads as well as pollutant concentrationws somewhat larger than those produced by the GQM simulations. The differences between SWMM and GQM results are likely to be caused by the differences in the wash-off rates rather than by the differences in the initial pollutant accumulations.

Finally, it has to be recognized that the water quality data base available in this study was too limited and did not allow the drawing of firm conclusions regarding the quality of urban runoff from the Malvern catchment. Numerous events have been monitored in the subsequent years and will be discussed in the forthcoming progress reports.

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APPENDIX

Rainfall, Runoff Quantity, and Runoff Quality Data Collected In the Malvern Catchment, 1974

APPENDIX

1974 Field Data

The 1974 field data that follow are divided into two groups. The first group comprises 17 events for which rainfall and runoff flow were recorded. All these data have been verified and are suitable for further analysis and interpretation.

The second group comprises five events for which rainfall, runoff flow, and runoff composition were monitored. The data in the second group are of limited value. They were collected during minor storms and served mostly for establishing procedures for the subsequent study years.

Rainfall and Runoff Flow Data

The rainfall and runoff flow data are given for storms no. 1-17. The rainfall records are typically described by the number of rain gauge tips (0.01" each) during one-minute intervals. For storm No. 2, the time interval was increased to five minutes. Only the times during which some rain was recorded or a rapid change in the runoff flow rate was observed were entered in the data tables.

For some events, the total rainfall depths given in the data tables are smaller than those shown earlier in Table 4. Such differences were caused by the calibration of rainfall data in Table 4 (using the calibration curve shown in Figure 3). The rainfall depths in the data tables were not calibrated, since the calibration correction depends on the rainfall intensity and may be affected by subjective interpretation of rainfall intensities (i.e., by the choice of time intervals for which the intensities are calculated).

Runoff hydrographs were measured continuously. To conserve space, they were described in the data tables by a limited number of data points (i.e., times and flow rates) which adequately described the hydrograph shape.

Rainfall/Runoff Flow/Runoff Composition Data

Rainfall, runoff flow, and runoff composition are presented for five storms (Nos. 18-22). The rainfall and runoff flow data are given in

the same format as described previously. The composition of runoff is given for the following five constituents:

- COD - chemical oxygen demand
- N - nitrates and nitrites
- P - total phosphorus
- SS - suspended solids (nonfilterable residue at 105°C)
- VSS - volatile suspended solids (VSS=SS - nonfilterable residue at 550°C).

The first three parameters - COD, N, and P - are given for liquid samples only.

Storm No. 1 - May 5, 1974

Time - hours and minutes	Raingauge tips (.01") each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1902	1		
20		0.00	0.000
24	1		
25		.02	.001
28		.07	.002
30	1	.20	.006
32	1	.58	.016
35		1.39	.039
38	1	2.17	.061
42	1		
46	1		
47		2.17	.061
50		2.06	.058
52	1		
55		2.06	.058
56	1		
2000	1	2.44	.069
02		2.44	.069
06	1		
11		1.88	.053
12	1		
16	1		
20	1	2.44	.069
26	1	2.44	.069
28	1		
30	1		
32	1		
33		4.75	.135
36	1		
37		4.75	.135
38	1		
40	1		
44	1		
46	1		
48	1	4.24	.120
50	1		
54	1		
57		2.77	.078
2100	1		
02	1	2.77	.078
05		2.96	.084
07		2.85	.081
2108	1		
10		2.44	.069
20		.95	.027
24	1		
30		.37	.010
40		.20	.006
50		.07	.002
2205		.02	.001

Storm No. 2 - May 8-9, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1755	1		
1805		0.00	.000
10		.02	.001
15	1	.07	.002
25	1		
30		.58	.016
35	1		
45	1	.95	.027
50	1		
1900	1	.95	.027
05	1	1.09	.031
10		1.39	.039
20	1	.82	.023
30		.58	.016
35	1		
40	1	.37	.010
2000	1		
05		.37	.010
10	1		
20		.58	.016
30	1		
40	1		
55	1		
2105	1	.58	.016
10		.82	.023
15	1	1.39	.039
20	1	1.71	.048
25	1		
30	1		
35	1		
40	1		
45	1	1.71	.048
50	1		
55	1	2.06	.058
2200	1	2.06	.058
10	1		
15	1	1.39	.039
20	1	1.39	.039
25	1		
27		2.44	.069
30	1	2.44	.069
35	1		
38		1.71	.048
40		1.54	.044

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
2245	1		
50	1		
55		1.23	.035
2300	1	1.39	.039
05	1		
10	1	1.71	.048
15	1	1.71	.048
25		.82	.023
30		.58	.016
40		.37	.010
2400		.13	.004
05	1		
10		.07	.002
25		.13	.004
50	1		
55		.13	.004
0100		.20	.006
05	1		
15	1	.82	.023
25		.58	.016
30	2		
38		2.25	.064
40	2		
48		2.25	.064
50	2		
55	2		
57		4.24	.120
0200	2	4.24	.120
05	1		
10	1		
15	1	2.44	.069
25		.95	.027
30	1	.95	.027
35	1	1.09	.031
45	1		
50		1.09	.031
0300		.58	.016
15		.13	.004
30		.05	.001
35	1		
36		.03	.001
38		.06	.002
40	1	.07	.002
45	2	1.09	.031
50	2	3.99	.113

Storm No. 2 - Continuation

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0355	2	4.49	.127
0400	2	4.90	.139
05	2	3.99	.113
11		2.44	.069
12		2.44	.069
15	2		
20	2	4.24	.120
21		4.24	.120
25	1	3.29	.093
30	1	2.06	.058
35	1	1.71	.048
37		1.54	.044
40	1		
45		1.71	.048
50	1	1.09	.031
55	1		
0500	1		
02		1.39	.039
07		1.39	.039
10	1		
20	1	.82	.023
32		.82	.023
35	2		
40	1		
42		2.06	.058
50	1		
55		.82	.023
0600	1	.82	.023
05		.95	.027
10	1	.95	.027
15		.82	.023
20	1	.82	.023
30	1	1.09	.031
35	1	1.09	.031
50	1	0.70	.020
0700	1		
05		.70	.020
25	1	.28	.008
35		.28	.008
40	1		
42		1.09	.031
45		1.09	.031
0800		.28	.008
10	1		
15		.09	.003

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0900		.07	.002
20	1		
25		.02	.001
30	1	.07	.002
35	2	1.54	.044
37		2.06	.058
45	2		
46		2.06	.058
50	2		
55	2		
1000	2	4.24	.120
05	3	5.87	.166
10	1	4.75	.135
15	2		
16		4.24	.120
20	3		
23		5.87	.166
25	2	5.58	.158
30	1		
35		1.71	.048
40	1	1.39	.039
47		1.39	.039
55	1	.82	.023
1105	1		
10	1	.82	.023
15	1		
20	1	2.25	.064
25		2.25	.064
35		.82	.023
45	1	.37	.010
1205		.07	.002

Storm No. 3 - May 15, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0733	1		
37		0.00	.000
39	1		
40		.07	.002
42	1		
45		1.39	.039
47	1		
48		2.06	.058
50		2.06	.058
53	1		
55		1.60	.045
57		1.40	.040
59	1		
0800	1	2.06	.058
02	1	3.75	.106
04	1		
05		4.90	.139
06		4.90	.139
07	1		
10		3.75	.106
12	1		
15		2.06	.058
20		1.23	.035
30		.58	.016
40		.28	.008
50		.13	.004
59	1		
0900		.07	.002

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 4 - May 16-17, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1532	1		
40		.00	.000
42	1		
43		.02	.001
44	1		
45		.37	.010
47	1		
48	1		
49		2.44	.069
52		2.85	.081
55		2.06	.058
1600		1.09	.031
02	1		
05		.82	.023
07	1		
10		1.23	.035
12	1		
13	1		
14	1		
15	1	5.30	.150
17	2		
18	2	11.52	.326
19	1		
20		11.94	.338
22	1		
26		7.76	.220
27	1		
28	1		
29	1		
30	1	5.87	.166
38	1		
40		1.88	.053
45		1.23	.035
46	1		
48		1.23	.035
49	1		
53	1		
54	1		
55		3.75	.106
58	1		
59	1		

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1700		5.30	.150
02	1		
04	1		
06		5.30	.150
08	1		
10	1	5.02	.142
12	1		
13	1		
16		5.02	.142
18	1		
24	1		
25		2.44	.069
28	1		
30	1		
34	1		
35		3.51	.099
39	1		
51	1		
55		.82	.023
1815		.20	.006
40		.02	.001
1942	1	.02	.001
45	1		
50		.37	.010
2000		.37	.010
05	1	.37	.010
08	2		
09	3.5		
10	3.5	18.18	.515
11	1		
12		20.42	.578
13	1		
15		10.70	.303
16	1	7.76	.220
19	1	11.11	.315
22	3	7.76	.220
23	1		
24	1		
25		11.52	.326
27	1		
28		7.76	.220
30		5.30	.150
31	1		

Storm No. 4 - Continuation

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
2034	1		
35		3.51	.099
40		2.44	.069
45		1.39	.039
46	1		
50		1.09	.031
54	1		
55		.95	.027
2100		.82	.023
10		.37	.010
21	1		
35		.37	.010
50		.13	.004
2215		.13	.004
18	2		
19	2		
20	1	5.87	.166
21	1		
22		9.17	.260
23		8.45	.239
24	1		
25		6.47	.183
28	1		
30		.82	.023
35		.37	.010
40		.07	.002
45		.02	.001
0127	1		
30		.00	.000
32		.20	.006
34	3		
35	3	13.25	.375
36	3.5	24.08	.682
37	3.5	25.39	.719
38	1		
43		7.76	.220
44	1		
45		5.30	.150
48	1		
50		3.29	.093
52	1		
55		3.06	.087
56	1		

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0200		2.64	.075
05		1.71	.048
10		.82	.023
15	1	.58	.016
45	1	.20	.006
50		.37	.010
53	1		
58	1		
0302	1		
05	1	2.64	.075
09	1		
13	1		
15	1	3.99	.113
18	1		
20		3.75	.106
22	1		
35		.95	.027
44	1		
50		.37	.010
0400		.20	.006
30		.07	.002

Storm No. 5 - May 31, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1903		.00	.000
05		.20	.006
06	2	7.76	.220
07	4	15.11	.428
08	4	21.60	.612
09	4	26.73	.757
10	1	29.57	.837
11		26.73	.757
12	1	21.60	.612
14	1		
15	2	11.52	.326
17	1		
19	1	8.45	.239
20	2	8.45	.239
22	1		
23	2	9.54	.270
25		12.37	.350
26	1		
27	2	21.60	.612
28	4	26.73	.757
29	3	29.57	.837
30	3		
31	5		
32	4		
33	2		
34	1	31.82	.901
35	2	31.06	.879
36	1		
37		20.42	.578
38	1		
39		15.11	.428
41	1		
43	1	7.76	.220
45		5.87	.166
48		3.75	.106
50		2.44	.069
55		1.09	.031
2000		.70	.020
05		.37	.010
10		.28	.008
15		.20	.006
35		.07	.002

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 6 - June 19, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0720	1		
33	1	.00	.000
35	1	.02	.001
38	2		
40	1		
42	1		
45		2.06	.058
48	1		
50		2.44	.069
53	1		
59	1		
0805		1.88	.053
07	1		
13	1		
17	1		
19	1		
20		2.44	.069
23	1		
24	1		
28	1		
30		3.51	.099
33	1		
45		1.39	.039
46	1		
55		.47	.013
0910		.13	.004
30		.07	.002
1000		.02	.001
20		.02	.001
32	1		
45		.20	.006
48	1		
50		.37	.010
53	1		
1100		1.39	.039
01	1		
07	1		
10		1.78	.050
13	1		
15		1.71	.048
20		1.39	.039
22	1		
28	1		

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1130		1.39	.039
45		.47	.013
48	1		
50	1	.58	.016
53	1		
56	1		
57	1		
58	1		
1200	2	4.75	.135
02	1		
05	1	6.05	.171
07		6.17	.175
13	1		
15		2.44	.069
20		1.54	.044
21	1		
40		.58	.016
54	1		
1300		.28	.008
20		.07	.002
30		.07	.002
40		.28	.008
1400		.07	.002
10		.28	.008
20		.07	.002
21	1		
26		.07	.002
28	1		
30		.28	.008
32	1		
35		1.23	.035
37	1		
39	1		
40		2.44	.069
43	1		
45		3.29	.093
47		3.29	.093
48	1		
1500	1		
03		1.09	.031
05	1	1.09	.031
08	1		
10		1.54	.044

Storm No. 6 - Continuation

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1515	1		
20	1	2.25	.064
25		2.44	.069
26	1		
28	1		
30		2.85	.081
35		2.44	.069
38	1		
40		1.88	.053
43	1		
48	1		
50		1.88	.053
53	1		
55		2.25	.064
56	1		
57		2.25	.064
1605	1	1.39	.039
07		1.39	.039
13	1		
15		1.71	.048
16	1		
19	1		
20		3.29	.093
22	1		
23	1		
24	1		
25		5.02	.142
30		3.75	.106
32	1		
35		2.06	.058
38	1		
40		1.54	.044
45	1	1.54	.044
48	1		
52	1		
53	1		
55		3.75	.106
1705		1.39	.039
06	1		
15		.82	.023
21	1		
30		.58	.016

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 7 - June 21, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1744	1		
45		.00	.000
46	1		
50		.02	.001
55		.05	.001
57		.20	.006
58	1	.82	.023
59		4.24	.120
1800	4	11.52	.326
01	4	16.10	.456
02	4	20.42	.578
03	3	20.42	.578
06		13.25	.375
07	1		
08	1	10.70	.303
09	2		
10	1		
11	1	11.94	.338
12	1	9.92	.281
13	1		
18		4.24	.120
20		2.64	.075
25	1	1.39	.039
30		.70	.020
40		.28	.008
50		.13	.004
1900		.07	.002
15		.02	.001

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 8 - June 30, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0837	1		
43		.00	.000
45		.02	.001
46	1		
47		.07	.002
50		.37	.010
51	1		
53	1		
55		2.20	.062
56	1		
58	1	3.70	.105
59	1		
0900		4.50	.127
02		4.80	.136
03	1		
05	1		
06		4.80	.136
08	1		
09	1		
10		4.60	.130
13	1		
14	1		
15		4.95	.140
17	1		
18		4.60	.130
19	1		
20		4.00	.113
25		2.10	.059
30		1.10	.031
35		.60	.017
40		.35	.010
45		.30	.008
50		.20	.006
55		.13	.004
1000		.08	.002
10		.04	.001
20		.00	.000

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 9 - July 4, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1910		.02	.001
11	2	.07	.002
12	3	.58	.016
13	3	3.29	.093
14	3		
15	4	14.16	.401
16	2	21.60	.612
17	1	25.39	.719
18	1	27.21	.770
19	1		
20	0	21.01	.595
22	1		
23	1		
24	0		
25		8.10	.229
26	1		
30		3.29	.093
35		2.06	.058
40		.70	.020
45		.37	.010
50		.28	.008
55		.20	.006
2000		.13	.004
10		.07	.002
30		.02	.001

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 10 - July 19, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0330		.00	.000
33		.02	.001
34	2		
35	1	1.09	.031
36	1		
37	1		
38	1	16.10	.456
39	2		
40	3	24.08	.682
41	3	24.08	.682
43	1	19.28	.546
44	1		
45		14.63	.414
46		11.52	.326
47		7.10	.201
50		2.85	.081
55		1.09	.031
0400		.58	.016
05		.28	.008
10		.20	.006
25		.07	.002
45		.02	.001

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 11 - September 2-3, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
2200		.02	.001
08	1		
13		.02	.001
18	1		
20		.07	.002
25		.20	.006
30	1	.28	.008
35		.37	.010
37	1		
40		.50	.014
45		.58	.016
46	1		
50		.82	.023
54	1		
55		.95	.027
2301	1		
02		.95	.027
04	1		
08	1		
10		2.06	.058
12	1		
15		2.25	.064
16	1		
18	1		
20		2.33	.066
23	1		
25	1	2.76	.078
28	1		
32	1		
35	1		
37		2.76	.078
38	1		
40		2.85	.081
43	2		
45	1	4.24	.120
47	1		
48	1	4.86	.138
49		4.86	.138
50		4.75	.135
53	1		
55		2.85	.081
58	1		

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
2400		2.06	.058
04	1		
05		2.06	.058
10		1.54	.044
15		.95	.027
18	1		
20		.70	.020
35		.58	.016
39	1		
0105		.17	.005
30		.05	.001
38	1		
0200		.07	.002
25	1	.07	.002
30		.13	.004
38	1		
45		.47	.013
48	1		
55	1	.82	.023
0302		.95	.027
05		.95	.027
08	1		
15		.70	.020
20	1		
30		.58	.016
35	1		
38		.58	.016
45	1		
50		.70	.020
52		.70	.020
0400	1		
10		.58	.016
13	1		
29	1		
43	1		
45		.58	.016
52	1		
0500	1	.95	.027
08	1		
13		1.18	.033
17	1		
20		1.09	.031
24	1		

Storm No. 11 - Continuation

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0532	1		
35		1.09	.031
40	1	1.23	.035
59	1		
0600		.82	.023
04	1		
10		.70	.020
15	1		
20		.70	.020
26	1		
33	1		
35		.88	.025
41		1.09	.031
42		1.09	.031
44	1		
45		.95	.027
55		.58	.016
0700		.47	.013
01	1		
20	1		
23		.37	.010
31	1		
35		.58	.016
45	1	.70	.020
0800		.37	.010
05		.28	.008
25		.07	.002
0900		.02	.001

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 12 - September 12, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0700	1		
04	1		
08	1		
13	1		
18	1		
20		.01	.000
21	1		
25		.02	.001
30		.58	.016
34	1		
40		1.71	.048
45		1.71	.048
55		.82	.023
0805		.37	.010
15		.20	.006
30		.13	.004
0910		.05	.001
1008	1		
10		.03	.001
11	1		
13	1		
15		.13	.004
16	1		
18	1		
19	1		
22	1		
23	1		
26	1		
28	1		
29	1		
30		1.71	.048
31	1		
33	1		
35	1	2.85	.081
38	1		
40		4.49	.127
42	1		
45		5.02	.142
46	1		
48	1		
50	1	5.58	.158
55	1	4.75	.135
1105		2.85	.081
10		3.06	.087
15		2.44	.069
25		.95	.027
35		.37	.010
45		.28	.008
1200		.13	.004
06	1		
17	1		
25	1		
28	1		
30	1		
33	1		
35		.02	.001
36	1		
37	1		
38	1		
40	1		
43	1		
45		.58	.016
47		1.09	.031
48	1		
51		2.85	.081
59		4.24	.120
1301		5.58	.158
02		5.58	.158
05		4.75	.135
06			
10		2.85	.081
20		1.09	.031
30		.47	.013
40		.20	.006
50		.13	.004
1400		.11	.003
20		.11	.003
35		.05	.001

Storm No. 13 - September 28, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0048	1		
0100		.00	.000
03	1		
05		.01	.000
08	1	.09	.003
12	1		
15	1		
18	1		
20	1		
22	1	4.24	.120
23	1		
25		4.75	.135
26	1		
29	1		
35		2.06	.058
40		1.23	.035
45		.70	.020
46	1		
50		.47	.013
0220		.07	.002
40		.02	.001
0319	1		
20		.01	.000
24	1		
25		.03	.001
30		.47	.013
35		.47	.013
49	1		
50		.20	.006
52		.20	.006
56	1		
58	1		
0400		1.39	.039
03	1		
05		3.06	.087
06	1		
07	1		
08	1	4.75	.135
09	1		
10		5.30	.150
13	1		
17		2.44	.069
19	1		
0420		2.06	.058
24	1		
25		1.88	.053
29	1		
30		2.06	.058
32	1		
35		2.44	.069
40	1		
45		.95	.027
50		.58	.016
55		.47	.013
56	1		
0500		.70	.020
05		.82	.023
10		.70	.020
15		.47	.013
30	1	.13	.004
37		.07	.002
0600		.03	.001

Storm No. 14 - September 28, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1910		.00	.000
12		.07	.002
13	2	.37	.010
14	3		
15	3	4.75	.135
16	2		
17	2	11.52	.326
18	2		
19	1	15.11	.428
20	1	14.63	.414
21	1		
25	1	7.10	.201
26	2	7.10	.201
27	1		
28	1		
29	1		
30	1	8.45	.239
31		8.45	.239
32	1		
34		7.10	.201
35	1	7.43	.210
36	1		
37	1	7.76	.220
38	1	9.92	.281
39	1		
40	2		
41	2		
42		11.52	.326
43	2		
44	1	11.52	.326
45		10.70	.303
46	1		
50		5.02	.142
51	1		
55		2.85	.081
56	1		
59	1		
2000		2.85	.081
04	1		
05		3.06	.087
06	1		
07	1		
09	1		

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
2010	1	4.75	.135
13	1		
15		5.02	.142
16	1		
17	1		
19	1		
20		3.99	.113
21		3.99	.113
22	1		
23	1		
24	1		
25	1	6.17	.175
27	1		
28		7.43	.210
29	1		
30	1	7.43	.210
33	1		
35	1	5.87	.166
37	1		
40		4.24	.120
45		2.25	.064
50		1.09	.031
55		.58	.016
2100		.28	.008
10		.13	.004
20		.07	.002
30		.05	.001
40		.02	.001

Storm No. 15 - November 5, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0958	1		
1000	1	.00	.000
01	1		
02	1		
03	1		
04		.58	.016
05	1	1.39	.039
07	1	3.29	.093
08	1		
09	1		
10		5.58	.158
11	1		
12		6.65	.188
13	1		
14	1		
15		6.65	.188
16	1		
17	1		
19	1		
20		6.35	.180
21	1		
22		6.17	.175
23	1		
24	1		
25	1	6.47	.183
27	1	6.47	.183
29	1		
30		5.87	.166
37		2.64	.075
38	1		
45		1.23	.035
49	1		
50		1.09	.031
53	1		
55		1.54	.044
56	1		
58		2.06	.058
1103	1	2.06	.058
07		1.88	.053
08	1	2.06	.058
10	1		
12	1		
13	1		
1115		3.75	.106
17		3.75	.106
18	1		
20		2.85	.081
25		1.71	.048
30		1.09	.031
40		.47	.013
50		.28	.008
1200		.13	.004
20		.04	.001
30		.02	.001

Storm No. 16 - November 20, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
0938		.00	.000
39	1		
40		.03	.001
41		.07	.002
43		.82	.023
44	3		
45	3	3.51	.099
46		4.75	.135
48		7.10	.201
49	1		
50		5.87	.166
53	1		
55		3.29	.093
57		3.29	.093
58	1		
59	1		
1002		4.24	.120
03	1		
06	1	4.24	.120
08	1		
10		3.75	.106
15		2.44	.069
19	1		
20		1.39	.039
25		.95	.027
26		.95	.027
27	1		
29	1		
30		1.39	.039
33	1		
35		2.25	.064
37		2.25	.064
40		1.71	.048
45		1.09	.031
50		0.70	.020
55		.37	.010
1100		.28	.008
06		.28	.008
13		.39	.011
18		.39	.011
30		.28	.008
40		.13	.004
50		.07	.002
1200		.04	.001

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)

Storm No. 17 - November 20, 1974

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1440	1		
45	1	.00	.000
50		.37	.010
51	1		
54		1.39	.039
58	1		
1500		1.54	.044
03	1		
10		1.39	.039
12		1.37	.039
13	1		
15	1	1.54	.044
18	1	2.06	.058
20		3.51	.099
21	1		
22	2		
23	1		
24	1	8.81	.249
25		8.81	.249
26	1		
27	1		
29	1		
30		6.47	.183
33	1		
35		4.75	.135
37	1		
40		2.85	.081
42	1		
50		1.54	.044
52	1		
55		1.54	.044
57		1.71	.048
58	1		
1600	1		
02	1		
04	1	4.49	.127
06	1	4.78	.135
09	1		
10		4.78	.135
13	1		
20		2.25	.064
25	1	1.39	.039
30		.95	.027

Time - hours and minutes	Raingauge tips (.01" each)	Runoff Flow Rate (cfs)	Runoff Flow Rate (m^3/s)
1633	1		
35		.82	.023
40	1	1.09	.031
45		1.39	.039
50		1.23	.035
1700		.58	.016
10		.28	.008
20		.17	.005
30		.07	.002
45		.07	.002

Storm No. 18 - September 28, 1974

Time Hours and Minutes	Observed Rainfall Raingauge Tips .01" Each	Observed Flow Rate (cfs)	(m^3/s)	Observed Constituent Concentrations (mg/l) COD	N	P	SS	VSS
0059		.25	.007	160	.19	.41	242	47
0103	1							
05		.49	.014	105	.70	.62	113	29
08	1							
12	1	1.15	.033	39.6	.05	.37	46	12
15	1							
18	1	2.51	.071	39.2	.60	.32	24	7
20	1							
22	1							
24	1							
25		3.39	.096	40.0	.70	.47	74	17
26	1							
29	1							
31		2.65	.075	36.0	.26	.50	46	11
38		1.34	.038	40.1	.25	.62	38	11
44		.84	.024	24.4	.30	.31	16	5
51		.57	.016	35.5	.35	.25	18	6
57		.65	.018	27.5	.35	.23	8	3
0204		.59	.017	33.3	.41	.21	8	2

Storm No. 19 - November 14, 1974

Time Hours and Minutes	Observed Rainfall Raingauge Tips .01" Each	Observed Flow Rate (cfs)	Observed Flow Rate (m^3/s)	Observed Constituent Concentrations (mg/l) COD	N	P	SS	VSS
0208		.47	.013	14.6	.95	.051	5	2
14	1	.47	.013	28.2	1.30	.088	21	7
21		.82	.023	21.9	1.20	.088	19	6
23	1							
27		1.09	.031	19.9	.95	.045	4	2
31	1							
34		1.23	.035	19.4	1.10	.068	16	7
38	1							
40		1.39	.039	20.9	1.00	.058	12	5
47		1.39	.039	9.2	1.10	.051	9	4
48	1							
53		1.23	.035	8.7	.96	.046	5	3
59	1							
0300		1.09	.031	6.8	.96	.045	6	3
06		1.09	.031	15.6	1.70	.051	8	4
08	1							
13		1.09	.031	7.3	1.10	.039	4	2
19	1	1.09	.031	8.7	.98	.047	9	4
26		1.09	.031	8.7	.91	.043	6	2
28	1							
32		1.09	.031	8.7	.94	.050	10	5
38	1							
39		1.09	.031	8.3	1.00	.056	7	3
45		1.23	.035	7.3	.93	.140	6	3
47	1							
52		1.23	.035	4.4	.95	.059	4	2
58		.95	.027	6.8	.95	.053	6	3
0405		.82	.023	3.9	.95	.040	3	2
08	1							
11		.58	.016	7.8	.92	.050	5	2
18		.52	.015	5.3	1.00	.040	4	2
24		.47	.013	3.4	1.30	.068	2	1
31		.30	.008	3.4	1.20	.040	2	1
37		.10	.003	6.8	1.40	.042	5	2

Storm No. 20 - November 20, 1974

Time Hours and Minutes	Observed Rainfall Raingauge Tips .01" Each	Observed Flow Rate (cfs)	Observed Flow Rate (m^3/s)	Observed Constituent Concentrations (mg/l) COD	N	P	SS	VSS
0455	1							
0515	1							
17		.02	.001	8.3	.43	.030	12	2
23		.04	.001	77.8	.61	.033	8	2
30	1	.08	.002	78.7	1.20	.031	6	1
36		.11	.003	82.0	.92	.032	5	1
43		.16	.005	30.6	1.30	.081	4	1
49		.22	.006	25.8	1.90	.041	4	1
56		.27	.008	4.4	2.30	.031	5	3
0602		.36	.010	5.0	2.70	.030	4	1
09		.32	.009	5.3	3.20	.028	4	2

Storm No. 21 - November 20, 1974

Time Hours and Minutes	Observed Rainfall Raingauge Tips .01" Each	Observed Flow Rate (cfs)	Observed Flow Rate (m^3/s)	Observed Constituent Concentrations (mg/l) COD	N	P	SS	VSS
0938	1							
43	2	.47	.013	178	1.1	.41	190	48
44	2							
45	2							
49	1	7.10	.201	96	.59	.25	191	55
53	1							
55		3.51	.099	58.8	.55	.19	103	24
58	1							
59	1							
1002	1	4.24	.120	46.6	.48	.18	101	21
05	1							
08	1	3.99	.113	40.7	.40	.21	116	14
15		2.50	.071	27.0	.40	.08	30	7
18	1							
21		1.39	.039	11.8	.40	.09	32	8
27	1							
28		1.00	.028	5.4	.44	.095	40	7
29	1							
33	1							
34		2.06	.058	10.4	.32	.09	31	3
41		1.88	.053	9.5	.34	.06	17	4
47		1.09	.031	17.0	.34	.065	22	6
54		.58	.016	25.4	.46	.065	14	5
1100		.37	.010	17.3	.46	.055	12	3
03	1							
07		.28	.008	17.0	.53	.065	15	3
13		.47	.013	16.5	.66	.085	30	6
20		.47	.013	73.5	.79	.080	13	3
34	1							

Storm No. 22 - December 7, 1974

Time Hours and Minutes	Observed Rainfall Raingauge Tips .01" Each	Observed Flow Rate (cfs)	Observed Flow Rate (m^3/s)	Observed Constituent Concentrations (mg/l) COD	N	P	SS	VSS
0031	1							
39	1							
42		.29	.008	54.1	.31	.16	85	30
46	1							
49		.36	.010	104.0	.38	.22	104	34
54	1							
55		.57	.016	99.2	1.70	.22	134	45
58	1							
0102	1	.84	.024	54.1	.30	.14	68	21
06	1							
08		1.38	.039	85.7	.30	.20	107	35
11	1							
15		1.88	.053	113.0	1.10	.27	99	31
18	1							
21		2.12	.060	49.6	.28	.14	59	19
24	1							
28		2.17	.061	72.2	.30	.20	83	30
29	1							
34		2.16	.061	107.0	.70	.28	156	48
36	1							
41		2.17	.061	33.7	.29	.12	49	13
47		2.00	.057	31.7	.29	.11	44	12
54		1.50	.042	26.3	.30	.11	38	11

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